TEXT FLY WITHIN
THE BOOK ONLY

CONTENTS

* The numbers give pages.

CHAPTER VI

CHAPTER VII

CHAPTER VIII

CHAPTER IX

CHAPTER X

CHAPTER XI

CHAPTER I

NEWTON AND THE COLOURS OF THE SPECTRUM

Nature and Nature's laws lay hid in night ;
God said, " Let Newton be ! " and all was light.

Discovery of the Spectrum.—It was in the year 1666 that Isaac Newton carried out at Cambridge the experiments on the decomposition of white light by a prism, which were to

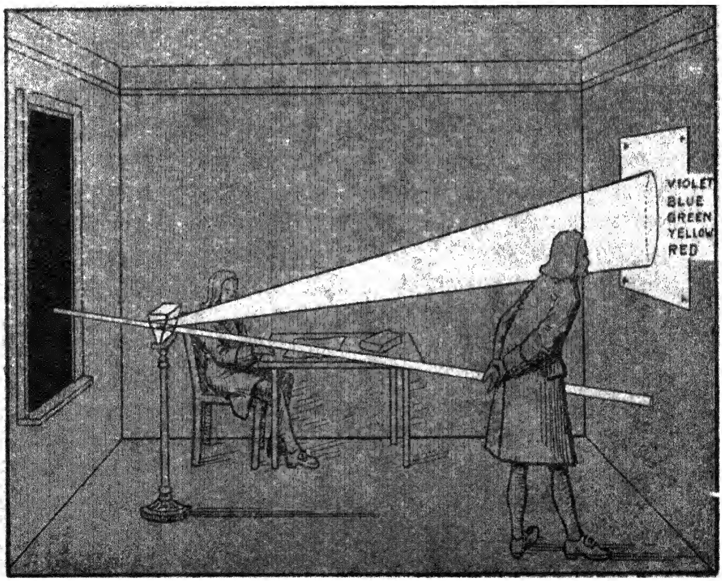


Fig. 1.

inform us as to the true nature of colour. As source of light he used the brightest of all possible sources, namely the sun. Its rays were admitted into a darkened room at Trinity

College through a hole in a shutter. In the first experiment on the spectrum described in the *Opticks*, this hole was circular and about $\frac{1}{3}$ inch in diameter. The rays then formed an image of the sun in its natural colour on the opposite wall of the room, the room acting as a pinhole camera. The image of the sun was about $2\frac{1}{8}$ inches in diameter.

If, however, a glass prism was placed inside the room close up to the hole, with its refracting edge horizontal and pointing downwards, so as to receive the rays, they were refracted or bent up, and the image of the sun appeared higher up on the wall as shown in Fig. 1. At the same time it changed its appearance. Instead of appearing as a single white disc when it was received on a sheet of white paper, it became a vertical strip with semi-circular ends. The strip was $18\frac{1}{2}$ ft. from the prism ; its breadth was $2\frac{1}{8}$ inches, just the same as the diameter of the image would have been, had the prism been taken away. The whole length of the strip was $10\frac{1}{4}$ inches and it was coloured. The lower end was red ; then followed in order the colours orange, yellow, green, blue, indigo and violet. The colours pass imperceptibly into one another through intermediate tints, and are not marked off by sharp boundaries. To the image Newton gave the name of the spectrum, and it is represented, pretty much as he saw it, in the coloured frontispiece.

In this way Newton discovered the solar spectrum, and a large part of the first book of his *Opticks* is devoted to proving what is a commonplace now, namely that white light is really composite, and that in decomposing it by the prism into the separate colours we are getting at something simpler and more elementary. The decomposition takes place partly at the first face and partly at the second face of the prism, as is shown in Fig. 2. On entering the glass the seven constituent rays

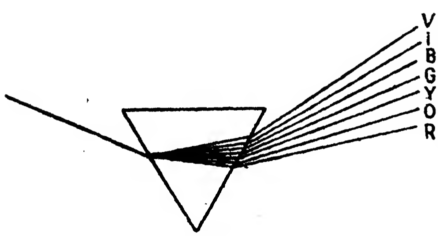


Fig. 2.

of the white ray are bent up to a different extent, and on leaving it the angles of divergence between each successive pair are further increased.

Let a beam of white light fall on a prism P, and form a spectrum VR (Fig. 3) on a piece of cardboard in which a narrow slit is cut. Then certain rays of the spectrum, for example, the green, will go through the slit. Now let these rays fall on a second prism Q, and afterwards be received on another piece of cardboard W. It is found that there is no further decomposition of the light; the green rays remain green after passing through the second prism, and the patch of light on the cardboard W is wholly green. Thus the green rays of the spectrum form something elementary that cannot be decomposed further. The same holds true of all the other colours of the spectrum, as may be shown by moving the slit in the first piece of cardboard, so that the other colours in succession pass through it.

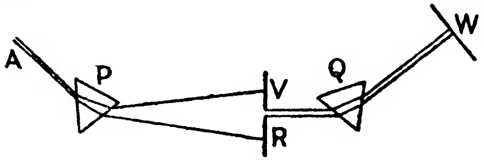


Fig. 3.

Not only can white light be decomposed into the seven colours of the spectrum, but they can be recombined together to form white light. Fig. 4 shows how Newton proved this. The prism forms a spectrum which could be received by a sheet of white cardboard at VR, but falls instead upon a

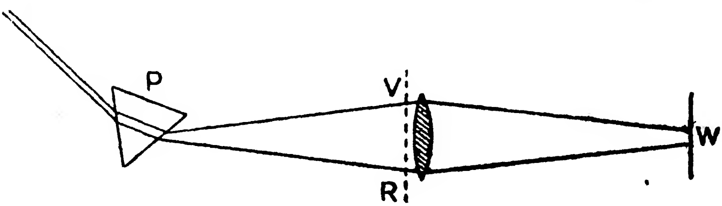


Fig. 4.

convex lens. This convex lens makes the different colours superimpose again, and they converge to form a white patch on a piece of white cardboard at W. If a pencil or similar

obstacle is held in front of the lens, so as to stop some part of the spectrum, then the patch at W appears coloured.

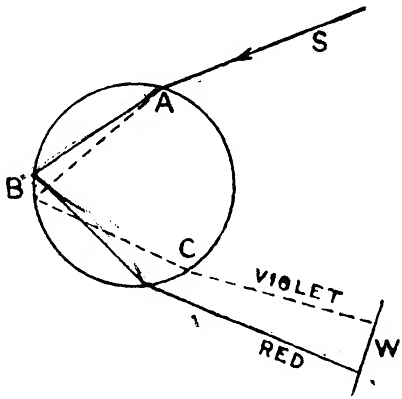


Fig. 5.

The Rainbow.—It is not necessary for the formation of a spectrum, that the prism should be made of glass; a hollow glass prism filled with water does as well. Even a drop of water acts under certain conditions in the same way as Newton's prism. For (Fig. 5), let SA be a ray of white light from the sun incident on a drop of water at A. On entering the water it is broken into a series of coloured rays, of which, for the sake of clearness, only the red and violet are drawn. These are reflected inside the drop at B and enter the air at C, when the angle between them is further increased. If a piece of cardboard is placed at W a spectrum will be obtained.

It is a spectrum of this kind that constitutes the rainbow. Fig. 6 illustrates the formation of the latter. A series of parallel rays from the sun which is behind the observer falls on raindrops, A, B, C, and the rays of a particular colour are reflected and enter the eye of the observer. The rays of the other colours which enter the eye are reflected either by drops higher up or lower down. The axis of the bow is parallel to the incident rays from the sun. The colours of the rainbow follow in the same order as the colours of the spectrum, but are not so distinct as in the spectrum. The violet is on the inside and the red on the outside of the bow. Rainbows are formed by the spray from cascades and waterfalls in the same way as by rainbows in the sky.

Views Previous to Newton.—The views prevalent about colour before Newton's investigation are described as follows in Dr. Barrow's optical lectures. Dr. Barrow was Newton's

friend and tutor, and Newton succeeded him in the Lucasian professorship of mathematics in 1669. "White is that which discharges a copious light equally clear in every direction.

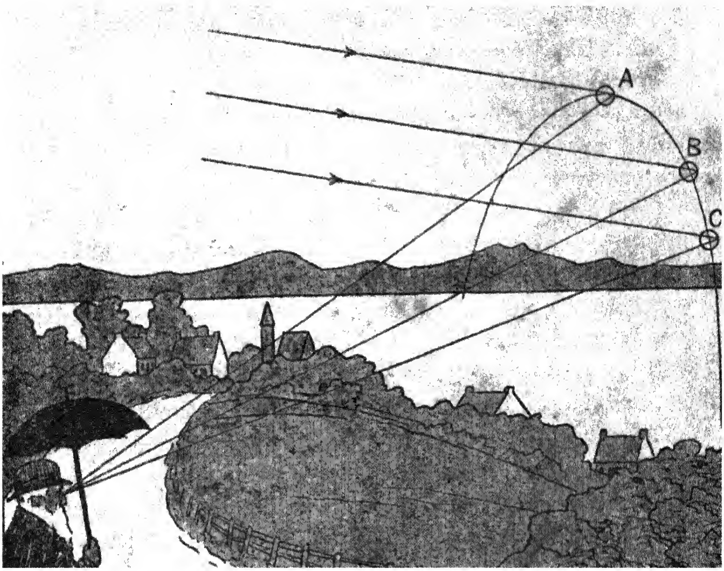


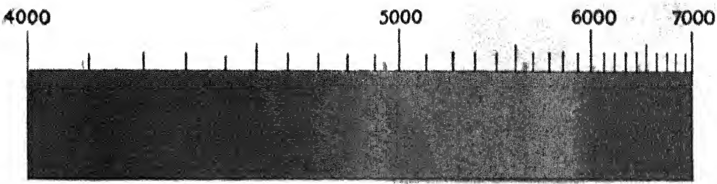
Fig. 6.

Black is that which does not emit light at all, or which does it very sparingly. Red is that which emits a light more clear than usual, but interrupted by shady interstices. Blue is that which discharges a rarefied light, as in bodies which consist of white and black particles arranged alternately. Green is nearly allied to blue. Yellow is a mixture of much white and a little red; and purple consists of a great deal of blue mixed with a small portion of red. The blue colour of the sea arises from the whiteness of the salt it contains, mixed with the blackness of the pure water in which the salt is dissolved; and the blueness of the shadows of bodies, seen at the same time by candle and daylight, arises from the whiteness of the paper mixed with the faint light of blackness of twilight."

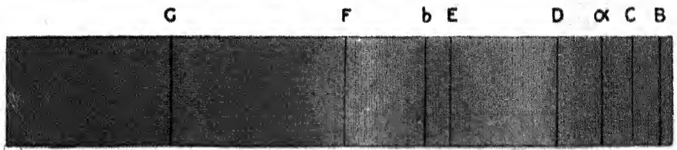
The above statement seems to the modern critic not far removed from nonsense.. No wonder in 1672 Newton referred to his own work in a letter to Oldenburg, the secretary of the Royal Society, as " being in my judgment, the oddest, if not the most considerable detection, which has hitherto been made in the operation of nature."

Spectrum Analysis.—Besides employing the sun as source of light for producing spectra Newton also used the planet Venus and the brightest of all the stars, Sirius. He says that the spectrum of Venus was not very bright, but still easily visible, and comments on its extreme narrowness. But his apparatus was not good enough for him to make much progress with the study of spectra. Although at times he used a rectangular slit and a lens, which is much nearer the modern arrangement than the first method of a simple round hole, still his prisms, which he apparently polished himself, were always of poor optical quality. One he mentions specially as having " Veins, running along within the Glass from one end to the other."

It was not until a century and a half after Newton's experiments, that progress was made at all in the study of spectra, and it was not until two centuries after Newton's experiments, that results were reaped on any large scale in this field. But the results obtained then were of the very highest importance. It was found that spectra, when examined under modern conditions, presented widely different aspects. For example in the coloured plate opposite, the first spectrum is what is known as a continuous spectrum. This is the kind given by the light from an incandescent electric lamp, a carbon arc lamp or a gas or paraffin oil flame, or even a red hot poker. The second spectrum is the solar spectrum, a continuous spectrum crossed by dark lines known as the Fraunhofer lines. The third spectrum consists of a single yellow or rather orange line, the sodium spectrum. This is obtained when any salt of sodium, washing soda, baking soda, common salt, is burned in a colourless flame. The usual manner of producing this spectrum is to heat a wire red hot, dip it into some baking soda, and then put it back into the flame, when the latter



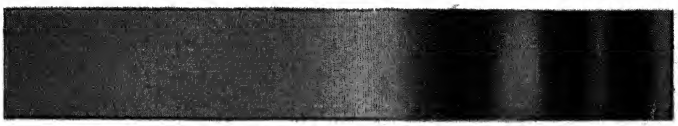
CONTINUOUS SPECTRUM



SOLAR SPECTRUM

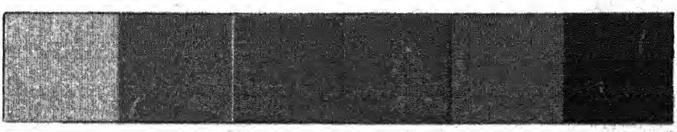
SODIUM FLAME

MERCURY ARC



COBALT GLASS

SWAN SPECTRUM



THREE COLOUR PRINTING

immediately colours a bright yellow. The fourth spectrum is a typical line spectrum, the spectrum of mercury vapour. This is the spectrum given by the Cooper-Hewitt lamp, a lamp which burns with a bright green light, and is used principally for advertising purposes or for making photographic prints. The fifth spectrum is what is known as an absorption spectrum. Suppose after an electric glow lamp is placed in front of the slit giving a continuous spectrum, that a sheet of blue glass coloured with cobalt oxide is placed between the lamp and the slit, then the spectrum is crossed by the three broad black bands. When the glass is removed, the bands disappear. The colours obscured by the bands are absorbed by the blue glass. The sixth spectrum known as the Swan spectrum after Prof. Swan of St. Andrews, who described it first, is an example of a band spectrum. It is given by the blue cone of the bunsen burner and by the blue edge at the base of a candle flame.

Now the spectrum is always characteristic of the light source. Whenever any compound of sodium is introduced into a flame, the yellow line appears. Hence the yellow line is an infallible means of detecting the presence of the element sodium. If the mercury lines appear, we know that mercury vapour must be present in the light source. In order to analyse any mixture and find out of what elements it is composed, it is only necessary to cause it to emit light, either by inserting it in a flame or in an electric arc, or by causing an electric spark to pass from it, and then to examine the spectrum of this light. This is the method of spectrum analysis.

It is the method by which we have determined the constitution of the sun and stars, results we could get at by no other way. If in the spectrum plate the solar spectrum be examined, it will be found that the dark line labelled D is exactly opposite the yellow sodium line. The natural explanation of this coincidence is that the body of the sun gives out a continuous spectrum, but that it is surrounded by a vapour which produces an absorption spectrum. And this vapour must contain sodium. Thus the presence of

sodium is detected in the sun. And so with the other elements. Indeed, one element helium was discovered in the sun by its dark line long before it was discovered on the earth.

On Seeing Indigo.—When Newton discovered the spectrum he divided it into seven colours, red, orange, yellow, green, blue, indigo, and violet. Most students have wondered why indigo was included in this list. For if we look along the spectrum from the one end to the other, screening off everything except the particular strip we are examining, we see in succession red, orange, yellow, yellow-green, green, green-blue, blue, blue-violet, and violet, but between the blue and the violet there is nothing sufficiently different in kind to warrant the introduction of a new name; the one colour merges gradually into the other, and the intermediate shades are clearly mixtures of blue and violet. Indigo as we know it from the water colour paint boxes, is an inky blue, a blue inclined to black, not one inclined to violet. The late Prof. S. P. Thompson used to state in his lectures, that indigo was more akin to green than to violet, and in this opinion, I think, every one will concur. What did Newton understand by the colour indigo, and why did he attach such importance to it?

Dr. Edridge-Green states that Newton had exceptionally good colour vision, and that he saw a difference in the spectrum at this point which was not visible to the average man. According to Edridge-Green's classification of colour vision the average man sees only six colours in the spectrum, red, orange, yellow, green, blue, and violet. He consequently refers to normal colour vision as hexachromic, the name being derived from the Greek for six colours. The average man sees, of course, intermediate shades between these colours, but these six colours appear to be fundamental. But there are certain individuals, the seven-colour class or hepta-chromic according to Edridge-Green's terminology, who see a seventh colour, indigo, between the blue and the violet. They have a decidedly better colour perception than the hexachromic. It is not merely a matter of colour nomenclature; the hepta-chromic really see something at this region in the spectrum,

which the hexachromic do not see. Newton, according to Edridge-Green, was a heptachromic.

I was at first somewhat sceptical about this explanation, because Newton states that his eyes were not so critical for distinguishing colours, as the eyes of his assistant, and the probability of both Newton and his assistant being heptachromic seemed to me too small. But out of eighteen observers taken at random I found that three at least saw indigo as a separate colour, and there was a fourth case doubtful. The others were normal. So the peculiarity appears to be fairly common.

The examination was made at first by projecting a spectrum about eight inches long on a screen. The student under examination was asked whether he saw a colour between blue and violet with as much right to a special name in the spectrum as orange had, and if so, how would he describe it, and what were its limits. The spectrum was that of a carbon arc with a somewhat sudden increase of brightness in the violet, and I was afraid this increase of brightness might be misleading. So those who said they saw indigo were taken to a spectroscope, shown a very good continuous spectrum, and asked again to mark the limits of indigo; also two of the four were shown narrow strips of the spectrum, and asked to say rapidly whether these were blue, indigo, or violet, an attempt being made to confuse them.

I had no difficulty in convincing myself, somewhat to my astonishment, that the four students referred to have a much better power of discriminating hues in this part of the spectrum than I have, and my colour vision is normal. They all objected to the word indigo, and chose dark blue as a more suitable name for the new colour; they all said it was more like blue than violet. They estimated the boundary between it and blue at 4650 A.U. (see scale above spectrum plate). At this part of the spectrum I see only blue merging into violet, and I find it extremely difficult to say where the one begins and the other ends, getting anything between 4370 and 4600 A.U.

It seems therefore beyond doubt, that both Newton and his

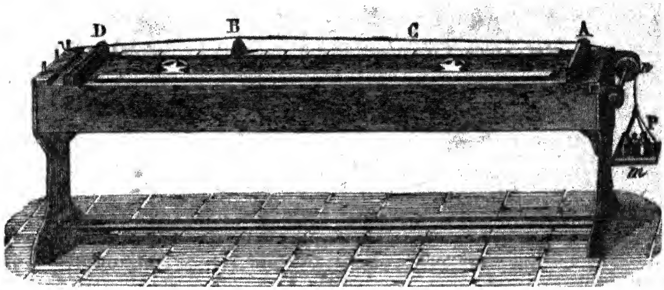
assistant had a somewhat different colour perception from the average for this region of the spectrum. This was, however, not the principal ground for the inclusion of indigo in the colours of the spectrum ; there is another reason both more important and more interesting. But, before describing it, it will be necessary to say something about the laws of vibrating strings.

Vibrating Strings.—If a violin string is bowed, or a piano wire struck by the hammer, it is set into vibration, and a musical note is heard. Such a refined arrangement, however, is not necessary ; even an elastic band stretched round the legs of a stool gives a note when plucked. The musical properties of stretched strings have been used from the earliest times in the lyre and allied instruments. One way of tuning the lyre was by fastening the strings to pegs which might be turned. In ancient times the lyre had originally only one tetrachord, *i.e.*, four strings, the highest and lowest in pitch being separated by the musical interval known as a fourth, the interval between c and f on the piano. Afterwards a second tetrachord was added, and other intervals, the fifth and octave, used.

Now it was found by Pythagoras (572–492 B.C.), that when a stretched string was plucked to give a certain note, and then the length of the vibrating portion diminished to one-half and plucked again, the tension being kept constant, the string gave out a note exactly one octave higher. If the length of the vibrating portion was diminished to two-thirds of its original value, it gave out a note one-fifth higher, *i.e.*, the interval from c to g on the piano, and if the length of the vibrating portion was diminished to three-quarters of its original value, it gave out a note one-fourth higher. It was probably known before Pythagoras that the pitch of the note depended on the length of the string, but he was the first to discover the exact relation. How he did it we do not know, but Fig. 7 represents an arrangement used by students nowadays for verifying the result. DBCA is the string, usually a piano wire ; it is attached to a peg at D, passes over a movable bridge at B, over a fixed bridge at A, and then over

a pulley. Its end carries a pan of weights to give it the necessary tension. AB is the vibrating portion; the length of AB is measured on a scale, and can be altered by sliding B along the scale.

This discovery of Pythagoras was of immense importance for science, being the first instance in which nature was found obeying an exact numerical law, and we may regard Pythagoras on the strength of it as the forerunner of the mathematical physicists of to-day. He did have a glimpse of the



From Ganot's Physics.] Fig. 7.

possibilities of applied mathematics, of that science that has led to the prediction of eclipses exact to the second, the calculation of lenses, the designing of flying machines, etc. It was probably the great possibilities which lay in the application of mathematics to the processes of nature, that he intended to express in the famous dictum "Things are numbers," that became the motto of his school. All scientific discoveries are stated in too concrete and unqualified a manner at first. Or possibly at that age language lacked the precision for expressing the idea clearly. In any case he was before his time. His meaning escaped his successors, and the Greeks made extremely small progress in the physical sciences in comparison with their achievements in mathematics, literature, and art.

The immediate result of the discovery of Pythagoras was to fix the musical scale. According to Pythagoras the intervals between the successive notes of the major scale are as follows :—

do	re	mi	fa	so	la	si	do
	$\frac{9}{8}$	$\frac{9}{8}$	$\frac{256}{243}$	$\frac{9}{8}$	$\frac{9}{8}$	$\frac{9}{8}$	$\frac{256}{243}$

We have one tetrachord from do to fa, a tone from fa to so, and another tetrachord from so to do. If we take the frequency of the keynote as 24, the frequencies of the other notes are then as follows :—

do	re	mi	fa	so	la	si	do
24	27	$30\frac{3}{8}$	32	36	$40\frac{1}{2}$	$45\frac{9}{16}$	48

In the modern diatonic scale they are in the ratios

24	27	30	32	36	40	45	48

The difference between the two scales is not very great; the diatonic scale is simply a development of the Pythagorean, which is better suited to the requirements of harmony. The lengths of vibrating string that give the notes of the scale are inversely proportional to the frequencies of the notes.

The Spectrum and the Musical Scale.—On p. 92 of the *Opticks*, Newton describes how he allowed the spectrum to fall upon a piece of paper, and got an assistant " whose Eyes for distinguishing colours were more critical than mine " to draw lines on the paper round the boundaries of the different colours. Fig. 8, which is a simplified form of the diagram

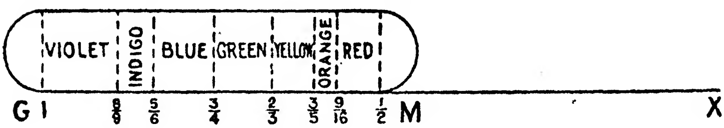


Fig. 8.

given in the *Opticks*, shows the nature of the result obtained. Then the base of the spectrum GM was produced to X making MX = GM, and it was found, that if the length of the whole line GX was taken as 1, the distances of the boundaries of the different colours were respectively $\frac{8}{9}$, $\frac{5}{6}$, $\frac{3}{4}$, $\frac{2}{3}$, $\frac{3}{5}$, $\frac{9}{16}$ and $\frac{1}{2}$ from X, and so represented the " Chords of the Key, and of a Tone, a third Minor, a fourth, a fifth, a sixth Major, a seventh, and an eighth above that Key."

This account is a little obscure. The *Opticks* was published in 1704, thirty-eight years after the experiments were made,

and eight years after Newton became Warden of the Mint. The parallel passage in the *Lectiones Opticae*, which according to their preface would have been published by Newton about 1671, had it not been for his dislike of controversy, is much fuller, and shows us his views in course of formation.

The passage describes how the spectrum was received upon a piece of paper, and the boundaries of the colours marked on the paper. Measurements were made on the lengths of the spaces occupied by the different colours. Then a diagram is given illustrating these measurements and showing the spectrum divided into five colours, orange and indigo being left out. In this diagram, however, the purest parts of the five colours do not occupy the middle of their spaces. So he introduces the two other colours; the purest part of each colour then occupies the middle of its space, and the spaces occupied are connected with the lengths of a vibrating string giving the notes of the octave. The spaces occupied by indigo and orange give the semitones, while the three spaces at the middle occupied by blue, green, and yellow, and the spaces at the ends occupied by violet and red give the tones. This scheme may suggest analogies between harmonies of sounds and of colours "*qualium pictores non penitus ignari sunt, sed ipse non dum satis perspectas habeo*"—such as are not wholly unknown to the painters, but which I have not studied sufficiently myself. In any case there is a similarity between the red and violet, the colours at the ends of the spectrum, of somewhat the same nature as that between the first and last notes of the octave.

To return to Fig. 8 then, the lines bounding indigo must correspond to *mi* and *fa* and consequently the violet end of the spectrum to *re*. The base line, therefore, gives the length of the string that should give *re*. Using the ratios of the numbers on the preceding page the lengths for the other notes should be

$$\frac{27}{30} \quad \frac{27}{32} \quad \frac{27}{36} \quad \frac{27}{40} \quad \frac{27}{45} \quad \frac{27}{48} \quad \frac{27}{54}$$

$$i.e. \quad \frac{9}{10} \quad \frac{27}{32} \quad \frac{3}{4} \quad \frac{27}{40} \quad \frac{3}{5} \quad \frac{9}{16} \quad \frac{1}{2}$$

which agrees fairly well with Newton's

$$\frac{8}{9} \quad \frac{5}{6} \quad \frac{3}{4} \quad \frac{2}{3} \quad \frac{3}{5} \quad \frac{9}{16} \quad \frac{1}{2}$$

Anyone comparing the account in the *Lectiones Opticae* written when Newton was a young man of 27 with the shorter and more reserved description in the *Opticks* must see that his early ideas had not been realised, and that nothing had come from the fancied analogy between the spectrum and the musical scale. And rightly so, for there is nothing in the analogy, though the possibility of there being some connection has exercised many minds since Newton's time. The measurements it was founded on are inaccurate, probably owing to the faulty nature of the prism ; Newton makes the yellow, for example, much too broad. It was found also after Newton's time, that the relative spacing of the colours depends on the nature of the glass of which the prism is constructed ; a flint glass gives different figures from a crown glass prism.

Indigo was introduced into the list of the colours of the spectrum in the attempt to find a connection between the spectrum and the musical scale. The attempt failed completely, but indigo remains in the list as a witness to it.

Newton's work on the spectrum is not widely known in this country, because his *Opticks* has not been printed in English since 1730, and because the part of the *Lectiones Opticae* or *Optical Lectures* bearing on the subject has never been printed in English. Newton's *Opticks* is for sale at present only in the German translation. The *Lectiones Opticae* containing Newton's principal discoveries on the spectrum were delivered in the University of Cambridge, in 1669, 1670 and 1671. It is said that the class was a small one, only of one or two students, and that one lecture was given each week. The lectures were given in Latin, and the Latin original was deposited in the archives of the university at the time it was read.

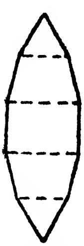


Fig. 9.

Newton and Chromatic Aberration.—A lens may be regarded as the limiting form of a prism with a number of faces, when the number is made very great (*cf.* Fig. 9). Now a prism bends the different

rays of light out their path to a different extent; it bends the violet most and the red least. Consequently we should expect the same to hold true of a lens. As a matter of fact, when a beam of white light is incident on a lens, the different colours in it converge to a different extent, and come to a focus at different points. Violet converges most, and red least, as is shown in Fig. 10. This difference in the positions of the foci, or chromatic aberration as it is called, is of importance in photography. We see chiefly by the yellow rays of the spectrum, and the photographic action

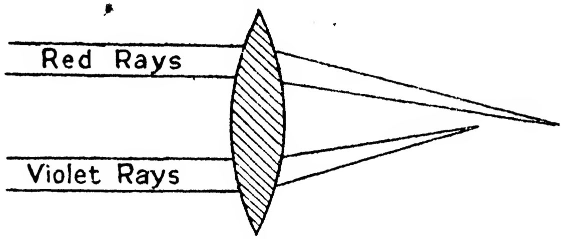


Fig. 10.

is due principally to the blue and violet rays. If a camera is fitted only with a single uncorrected lens, and the picture is focussed on the ground glass screen, the photographic rays are not in focus. There is a difference between the visual and the photographic foci, and the plate must be pushed a little towards the lens, if the picture is to be sharp. Chromatic aberration is also important for visual work; if the object

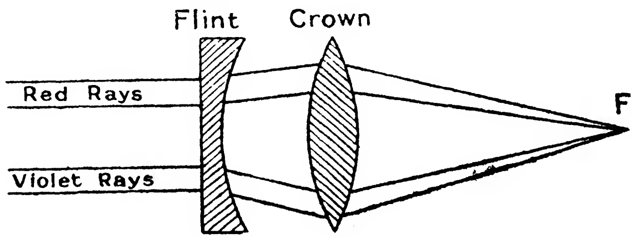


Fig. 11.

glass of a telescope were a single uncorrected lens, the images produced by the different colours would not occupy the same place, and would consequently blur one another.

Chromatic aberration is reduced to a considerable extent by combining a concave lens of flint glass with a convex lens of crown glass, as shown in Fig. 11. The concave lens bends the rays the other way from the convex in both cases, but does not bend the red to the same extent as the violet, so they come finally to the same focus F. For the sake of clearness the two lenses are shown separate in Fig. 11, but in actual practice they are always cemented together as in Fig. 12.

A prism both deviates the light, and spreads it out into a spectrum; the reason why it is possible to correct the convex lens by means of the concave one, is because in the case of the flint glass the spreading-out or dispersion bears a considerably greater ratio to the deviation than in the case of the crown glass. Thus the second lens neutralises the dispersion of the first without destroying all the convergence produced.

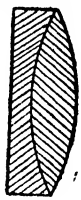


Fig. 12.

Newton was under the impression, that the spreading-out of the spectrum was always proportional to the deviation produced, no matter what kind of glass was used, and that consequently chromatic aberration was an insuperable obstacle to the development of the telescope object glass; he therefore turned his attention to mirror telescopes. We know that he worked with a hollow prism filled with water, which should have given a spectrum only half as long as his glass prisms did, and Lucas in Liege, who worked with a crown glass prism, insisted that his spectrum was only three times the angular diameter of the sun, not five times as Newton found it. Why Newton should have persisted in error has always seemed strange, and Glazebrook has suggested in his biography in the *Encyclopædia Britannica*, that possibly the water in Newton's hollow prism contained sugar of lead in solution; this would increase the length of the spectrum, and make it similar to the spectrum given by the glass prism. We know that Newton sometimes worked with sugar of lead solutions.

But was the whole affair not merely a matter of strong, preconceived ideas? The measurement of the deviation of the

different colours of the spectrum follows closely on the comparison of the spectrum with the musical scale, both in the *Opticks* and *Lectiones Opticae.* If the arrangement of the colours in the spectrum bore a fixed relation to the musical scale, it was obviously independent of the material of the prism. Thus Newton had a strong prepossession in favour of his error, and the experimental evidence forthcoming was not strong enough to disabuse him. Besides the years 1665–6, when he was occupied with the spectrum, were a time of such great mental activity on the part of Newton—they saw the discovery of the binomial theorem and differential and integral calculus, to say nothing of the work on gravitation—that he must have experimented at high speed. So he missed the credit of discovering the achromatic lens.

The Music of the Spheres.—Why did Newton seek to connect the spectrum and the musical scale ? He was probably influenced by Kepler's work, the *Harmonices Mundi* or *Harmonies of the Universe,* to which he would refer in connection with his work on gravitation.

Reference has already been made to the discovery of the laws of harmony or the laws of the vibrating string by Pythagoras. Since the first laws discovered were the laws of harmony, a law necessarily became a harmony. For example, the regular movement of the planets across the heavens was referred to as a harmony. Then the metaphor ran away with the astronomer, and the idea got abroad, that the seven planets emitted musical notes as they revolved in their orbits, the whole forming a heavenly harmony. This was the famous doctrine of the Music of the Spheres. Laws being regarded as harmonies, the musical scale became an idea in terms of which things had to be explained, just as we explain them in terms of force or evolution nowadays. So we have the *Harmonies* of Ptolemy and *Harmonices Mundi* of Kepler. The series known as the harmonical progression had a great importance. Modern science rests upon an experimental basis ; the student makes a fresh start from Galileo and Newton, and so is uninfluenced by the medieval tradition, which must have pressed upon the latter. But the harmonical

progressions remain as a curious survival in the text-books of algebra. The intelligent schoolboy always wishes to know why they are there; they are not much use for setting questions on, either problems or bookwork, because unlike arithmetical or geometrical progressions there is no expression to be proved for their sum to *n* terms, and they have no bearing on simple or compound interest.

The doctrine of the music of the spheres persisted for centuries without getting further on, or indeed ever attaining clear expression. Plato touches on it poetically in the myth of Er in the *Republic*, Book X. Aristotle deals with it in a characteristic matter-of-fact manner. In *De Caelo*, ii. 9, he thinks, that while it is a brilliant and remarkable suggestion on the part of its authors, still it is not true. He states, that it is argued the planets must make a sound, since bodies moving through the air at the surface of the earth do, the analogy being apparently with the whizzing sound of a stone flying through the air. Also we do not hear the tones of the planets, being in the condition of people who live in a smith's forge; from our births we are unceasingly hearing the same sound, and so are never in a position to take note of its existence from the contrast of silence. Nicomachus, Cicero, and Pliny all give diverging accounts of which planets correspond to which notes; none of these authors seem to have thought clearly or independently on the subject, and Pliny's knowledge of the musical intervals was inaccurate.

The simplest and oldest account of the music of the spheres is that given in the following scheme:

	576	Moon
Tone		
	648	Venus
Tone		
	729	Mercury
Semitone		
	768	Sun
Tone		
	864	Mars
Tone		
	972	Jupiter
Semitone		
	1024	Saturn

The ratios of the successive numbers are $\frac{9}{8}$, $\frac{9}{8}$, $\frac{256}{243}$, $\frac{9}{8}$, $\frac{9}{8}$, $\frac{256}{243}$; the numbers are simply the lowest integers that give these ratios. They are proportional to the lengths of strings

sounding the notes. Saturn consequently gave the lowest note and the moon the highest. If Saturn was sounding *si* on the Pythagorean scale (*cf.* p. 12), Jupiter was sounding *do*, Mars *re*, the sun *mi*, Mercury *fa*, Venus *so* and the moon *la*. None of the authors seem to have noticed that the combination would not be a "heavenly harmony," at least to mortal ears. The order of the "planets" in the table is that of their periods. The allocation of the different notes has apparently been guess-work. The determination of the lowest integers that give the ratios correctly is a sound piece of work; it is the first step in the process we can follow But the next step is a most wonderful one; the numbers allocated to the planets are assumed to represent their distances from the earth in stadia!

The music of the spheres forms a curious bypath in the history of human thought. And yet not altogether a bypath, for it inspired Kepler to discover the third law of planetary motion, and upon this law Newton built his theory of gravitation.

The Number Seven.—It will be noticed in the above scheme that the sun and moon are included in the number of the planets. This was the teaching of the priest-astronomers of the early Babylonian civilisation. Uranus and Neptune were, of course, not discovered then. The seven planets were regarded as gods, an idea that lingered on into medieval times in astrology; the sun's influence on the crops and weather was, of course, very obvious, and it became natural to assume that the other planets exerted an influence on human affairs, less obvious perhaps, but nevertheless very important. To a primitive pastoral people, often abroad at night under a clear tropical sky, the planets would naturally appear very mysterious moving on their regular paths among the stars. The division of the month into weeks was instituted in their honour, an arrangement still in use in this country with the names of the Scandinavian deities substituted. It was doubtless owing to there being seven planets, that the number seven acquired the sacred character it has in the Bible, that there were seven important metals in alchemy, that there were seven notes in the octave, and seven colours in the spectrum.

CHAPTER II

THE NATURE OF LIGHT

The Emission Theory.—What is the essential difference between the different colours of the spectrum ? Newton said they consisted of particles of different size, the red rays being the largest particles and the violet rays the smallest. Thomas Young said they consisted of waves of different length, the red rays being the longest waves and the violet rays the shortest. These two explanations are so important that it will be necessary to go into them at some length.

In science we explain things by analogy with other things. Now we can think of a ray of light as a jet of particles shot out from its source in somewhat the same manner as the bullets from a machine gun. These particles are extremely small, so that they can be emitted from the source for a long time without causing it to lose weight appreciably. They travel in straight lines ; thus the fact that rays of light are straight, finds a natural explanation. The particles are reflected by a mirror in somewhat the same way as a rubber ball rebounds from the floor, or as a billiard ball rebounds from the cushion. When the particles impinge on the retina in the eye, they cause the sensation of light. This manner of explaining the ray is called the emission theory of light.

Newton adopted the emission theory of light. In the first sentence of his *Opticks* he says " My design in this book is not to explain the Properties of Light by Hypotheses, but to propose them and prove them by reason and experiment," and he is very careful in pursuance of this design to make his statements as free from hypotheses as possible. Again and again he uses the word " ray," when it is obvious the thought in his mind is " stream of particles constituting the ray." But he eventually committed himself quite definitely : Light

consisted of streams of particles, the violet rays being the smallest particles and the red rays the largest; the glass of the prism attracted the particles in the ray incident on it, and this attraction caused the deviation of the ray; the smaller particles were attracted more strongly than the larger particles, and consequently suffered a greater deviation; hence the formation of the spectrum.

But, though Newton adopted the emission theory, he had misgivings on the subject. This is especially evident from a query, No. 13, which he appends to the end of his *Opticks* as a problem suitable for future investigation. This query starts, "Do not several sort of rays make vibrations of several bignesses, which according to their bignesses excite sensations of several Colours, much after the manner that the vibration of the Air, according to their several bignesses excite sensations of several sounds?" Then he suggests that the violet rays make the shorter vibrations and the red ones the longer vibrations.

Few great discoverers have been honoured and rewarded by their contemporaries as Newton was. In 1699 he was made Master of the Mint at a yearly salary of £1,500, he was knighted, was twice Member of Parliament, and was President of the Royal Society. When he died at the age of 84 in 1727, he was buried with the greatest ceremony in Westminster Abbey. During the last twenty years of his life he was regarded as an infallible authority by a great circle of pupils and adherents, and his views on light received the widest acceptance, more especially as his distinguished opponents, Huygens and Hooke, had predeceased him. His *Opticks* was regarded as of equal importance with his *Principia*, and his emission theory as of equal value with his law of gravitation.

The emission theory prevailed for a century after his death; this century was distinctly barren as regards advance both in experimental and theoretical optics. As is usually the case when a theory becomes old, the views of the Newtonian school hardened with time, the scruples of the master were forgotten, and his disciples became very intolerant of opposition. That opposition was to come first from Thomas Young.

Thomas Young was a genius of the first rank though not of the same mental stature as Newton. He was a physician by profession, but was professor of natural philosophy at the Royal Institution in London in 1802 and 1803; he regarded his scientific studies, however, as a recreation. He was also distinguished as an Egyptologist. He was a man of means, mixed largely in society, and was of a happy, tranquil disposition, unlike Newton who was irritable.

The Principle of Interference.—Young's great service to science was to establish the principle of interference. This is a principle by which, paradoxical as it may seem, you may add light to light and get as a result darkness. It is best explained by means of the waves which form upon the surface of a pool of water.

Suppose a stone is thrown into a pool of water; then waves travel out in all directions from the point at which it plunges below the surface. These waves can be followed by the eye as a series of ever widening circles, until they are lost at the edge of the pool. They consist of a procession of alternate crests and troughs; in front of them is smooth water and behind them is smooth water. Fig. 13 represents a train of five waves proceeding out from a centre P. They are seen from above and the black circles represent crests.

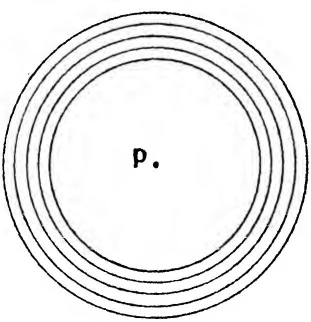


Fig. 13.

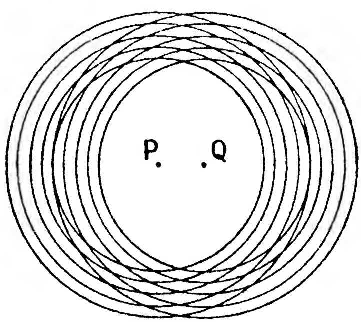
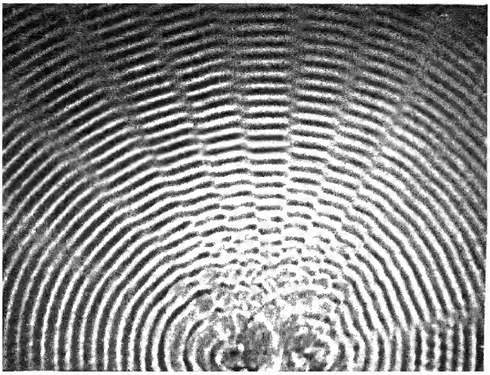


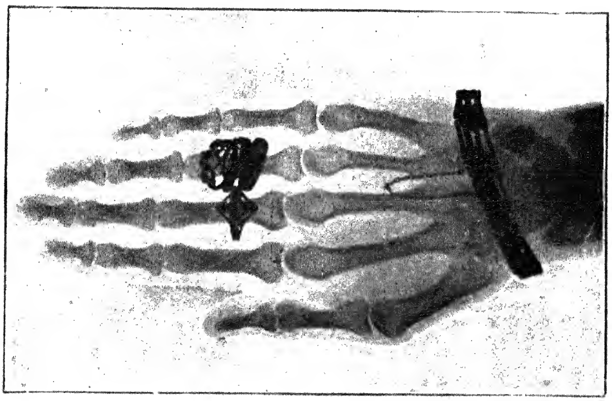
Fig. 14.

In Fig. 14 two stones have been dropped in simultaneously at P and Q, and two trains, each consisting of five waves, have been emitted. These trains are shown superimposed. Now when a crest is superimposed on a crest we shall have a



From Watson's Text-Book of Physics.

Photograph showing interference of two Wave-Trains on a Mercury Surface.



From Watson's Text-Book of Physics.

Radiograph of a Hand with Bracelet and Rings.

The bones are much more opaque than the flesh, but less opaque than the metal.

PLATE I.

crest twice as high ; when a trough is superimposed on a trough we shall have a trough twice as deep, and when a crest is superimposed on a trough, they will neutralise one another, and the level will be the same as if the surface had not been disturbed. This is shown in Fig. 15 ; the thick lines represent crests twice as high, and the spaces at their ends represent undisturbed level. As both halves of the diagram are the same, only the part above PQ has been drawn. It is possible to pass through the wave train from the front to the back along the dotted line and have undisturbed level the whole way. The one wave has neutralised the other or interfered with the other ; we have added wave-motion to wave-motion, and got as a result nothing.

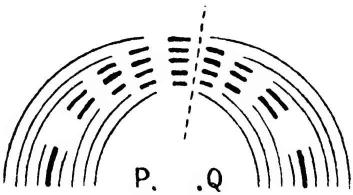


Fig. 15.

On Plate I is a photograph taken from above of two overlapping wave trains on a mercury surface. The regions where they neutralise one another can be distinguished quite clearly. Figs. 16 and 17 show another way of approaching the subject. *a* and *b* are two waves which superimpose with crest on crest

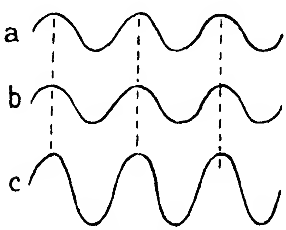


Fig. 16.

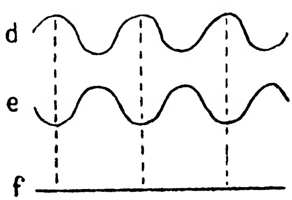


Fig. 17.

and trough on trough and give *c*. *d* and *e* are two waves which superimpose with crest on trough and trough on crest and give *f*. The crests fill up the troughs.

Suppose now a beam of light passes through a slit S and falls upon two parallel slits A and B. Then from A the beam ACD diverges, and from B the beam BEF diverges. These beams are received upon a piece of cardboard CF ; the middle

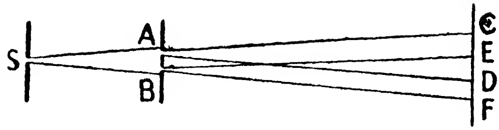


Fig. 18.

strip of the cardboard ED is illuminated by the overlapping portions of the beams ACD and BEF, *i.e.*, by light from both slits, while the strips CE and DF of the cardboard are illuminated only by light from one of the slits. We would expect all three strips to be uniformly illuminated, CE and DF being equally bright and ED twice as bright, since it receives light from both slits. But as a matter of experience this is not what happens, when the experiment is carried out under suitable conditions. The strips CE and DF are, it is true, uniformly illuminated, but the middle strip ED is covered with light and dark bands, interference bands as they are called. The experiment was first carried out by Young, and is usually known as Young's experiment. According to his explanation light waves are emitted from each of the slits A and B. Where crests reinforce crests we have bright bands on the cardboard ; where crests and troughs annul one another we have darkness. The experiment is an extremely difficult one to carry out.

The Wave Length of Light.—Young followed out the various applications of the principle of interference and came to the conclusion, that light must be propagated by wave motion. It seemed quite impossible to explain interference bands on the emission theory. He also calculated[1] the mean wave-

[1] The method by which the calculation was made is not easy to understand. A determination of the wave-length, however, might be made by Young's experiment, and in this case the reasoning is comparatively easy to follow. Let S be the single slit, A and B the

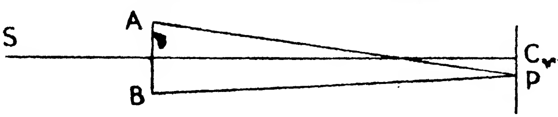


Fig. 19.

double slits, CP the cardboard screen, and let SC bisect AB at right angles. A and B are equidistant from S, so when a crest passes through

length of light of different colours from certain of Newton's observations. The second column of the following table gives his results; it is interesting as giving the first determination of the wave-length of light ever made. The values, it may be noted, are quite good enough for modern use.

COLOUR.	WAVE-LENGTH IN INCHES.	WAVE-LENGTH IN CENTIMETRES.
End of visible spectrum...	.0000266	.0000676
Red ...	.0000256	.0000650
Orange ...	.0000240	.0000609
Yellow ...	.0000227	.0000576
Green ...	.0000211	.0000536
Blue ...	.0000196	.0000498
Indigo ...	.0000185	.0000460
Violet ...	.0000174	.0000442
End of visible spectrum...	.0000167	.0000424

From the table we see, for example, that the wave-length of green light is $\frac{211}{10,000,000}$ inch, or there are 47,393 wave-lengths to the inch. The wave-length of light is thus an extremely small quantity. Young's results are given in

A, a crest simultaneously passes through B, and when a trough passes through A, a trough simultaneously passes through B. C is equidistant from A and B; hence the crests from A and B and the troughs from A and B will reach C simultaneously. The waves consequently reinforce at C. Now consider a point P near C. AP is longer than BP; consequently the waves will be out of step on reaching P. When the difference in path is half a wave-length, the two waves annul one another and we have darkness. When the difference in path is one wave-length, the waves reinforce one another again. It can be shown by elementary geometry that

$$AP - BP = \frac{2dx}{D}$$

where D is the distance of the screen from the double slits, $2d$ is the distance between the double slits, and $x = CP$. It is assumed that d and x are small in comparison with D. Consequently, if a is the distance between two adjacent bright bands, λ = the wave-length of light is given by

$$\lambda = \frac{2dx}{D},$$

and if x, d and D are measured, λ can be calculated.

inches. Nowadays it is customary in scientific work to express results in centimetres instead of inches, there being 2·54 centimetres to the inch; in the third column of the table I have calculated Young's results into centimetres. Wave-lengths of light are often expressed in Angström units, written A.U. for short, Angström being the name of a Swedish investigator who constructed a celebrated table of wave-lengths. There are 100,000,000 A.U. to the centimetre, so according to the table the wave-length of green light is 5360 A.U. Wave-lengths are also sometimes expressed in μ or $\mu\mu$; $1\ \mu = 1000\ \mu\mu = 10{,}000$ A.U. A scale of wave-lengths in A.U. is given at the top of the spectrum plate; hence it is possible to read off the values of the wave-lengths of the different lines on that plate.

Brougham's Attack on Young.—Young published his theory of light in three memoirs in the Philosophical Transactions of the Royal Society in 1802 and 1803. Together they constitute one of the most important advances ever made in physical science. But as soon as they appeared, they were attacked in the most savage manner in three articles in the *Edinburgh Review*, one article being devoted to each of the memoirs. The articles were by Henry Brougham, afterwards Lord Chancellor of England, who dabbled a little in science, and who it is said, was offended by a criticism made by Young on a paper he had written. There is nothing in Brougham's three articles worthy the name of serious criticism—it is clear he did not understand the principle of interference at all—but the articles were unsurpassed for sarcasm and power, and are historically important on account of the harm they did the development of the wave theory in Britain. As an example of Brougham's style we may quote the following sentences:

"Were we to take the trouble of refuting him, he might tell us 'My opinion is changed, and I have abandoned that hypothesis; but here is another for you.' We demand, if the world of science, which Newton once illuminated, is to be as changeable in its modes as the world of taste, which is directed by the nod of a silly woman or a pampered fop?

Has the Royal Society degraded its publications into bulletins of new and fashionable theories for the ladies who attend the Royal Institution? *Proh pudor!* Let the professor continue to amuse his audience with an endless variety of such harmless trifles; but, in the name of science, let them not find admittance into that venerable repository which contains the works of Newton, and Boyle, and Cavendish, and Maskelyne, and Herschel."

It is unfortunately true that invective and abuse have much more effect in swaying opinion than reason has, even amongst educated people, and there is no doubt whatever that Brougham's attack damaged Young's reputation, and diverted attention from his theory, at least amongst his own countrymen, for nearly twenty years. Consequently it was in France that the truth of the wave theory was first recognised, and its principles fully established.

Fresnel.—This was due to the work of one man, Augustin Jean Fresnel, a civil engineer in the service of the French Government. He was employed on the construction of roads. "This kind of life," he said in a letter, "although somewhat arduous, would suit me well enough, if I did not get tired, and if I was not worried with the anxiety of supervision, and the necessity for scolding and bullying my men," and in another letter he wrote, "I find nothing so laborious as leading men, and I confess I know nothing at all about it." As a distraction he began to study the theory of light. The political events of the time were to give him more leisure for his studies. In 1815 he joined the small army which attempted to oppose the return of Napoleon from Elba; as a consequence he was suspended from his duties, and put under police surveillance, but was afterwards allowed to retire to the village of Mathien, near Caen, where his mother lived. Here he pushed on his studies; he had few books and his apparatus was of the scantiest, but he was one of those who possess the gift for experimenting so well characterised by Franklin, when he said that the physicist ought to be able to saw with a file, and file with a saw. He made a micrometer with threads and pieces of cardboard; he had no heliostat for sending the sun's rays

in a constant direction, but he diminished the inconvenience due to the sun's motion by employing a lens of short focus; the village blacksmith also gave him some help. With this rough apparatus he obtained results which he presented in two memoirs to the Academy of Sciences at Paris. Arago, who was charged with examining these memoirs, was so much impressed by them, that he obtained permission from the Director-General of Roads and Bridges for Fresnel, who was now reinstated in his office, to come to Paris for some months in the beginning of 1816, to repeat his experiments under more favourable conditions.

These earlier memoirs were followed up by others, which in a few years put the wave-theory of light on a firm basis and completely overthrew the emission theory. Fresnel remained a civil engineer until his death in 1827 at the age of thirty-nine. But the heads of his department stationed him at Paris, so that he could have access to books, and having grasped the fact that they had a genius of the first rank in their employment who was quietly revolutionising the whole of optical theory, they put him on to the improvement of lighthouse lenses. Which was a highly creditable piece of initiative for a Government department.

We possess some very interesting letters written by Fresnel to Young. In spite of the political events of the time—Fresnel's elder brother was an officer in the artillery and died in Spain at the siege of Badajoz in 1807—they were on friendly terms. On one occasion, when overcome by excessive work and ill-health, Fresnel expressed himself in a peevish manner. But he afterwards expressed his regret for it. It is interesting, as a study in contrasts, to know that Young learned to read when he was two years old, but that Fresnel did not make much progress at it until after he was eight.

The Ether.—The emission theory prevailed for a century after Newton's death. The wave theory has prevailed in its place for another century, but now in its turn is being faced with difficulties. There is, however, one great difference between the situation now, and as it existed one hundred years ago. Then the wave theory presented a clear and

AUGUSTIN FRESNEL.

From an Engraving by E. Rosotte, after a Painting by A. Tardieu,
("Œuvres complètes d'Augustin Fresnel," Paris).

PLATE II.

definite alternative to the emission theory, explaining certain decisive experiments in a simple and natural manner. The critics of the wave theory at present are not so much hostile as neutral towards it; they present no alternative to it. But it will be better to describe first how the difficulties arise.

As we ascend up in the atmosphere, the air becomes thinner and thinner, and finally ceases altogether. The regions of space between the earth and the sun are completely devoid of ordinary matter. Now light comes from the sun by wave motion, and we cannot imagine wave motion without a medium for the waves to travel in. We consequently assume that there is a medium between the earth and the sun and stars, distinct from ordinary matter. This medium is called the luminiferous ether or simply the ether, sometimes spelt æther, to distinguish it from the ether that can be bought at the chemist's in bottles. The ether has no weight; it fills all space, and penetrates the interstices of matter.

The earth moves round the sun with a speed of 18½ miles per second. The question arises as to what happens to the ether within the earth's body and the earth's atmosphere. Is it carried with the earth like the air in the carriage of a railway train when the windows are shut, or does the earth move through it like a wire framework swinging in still air, or does something of an intermediate nature happen? These alternatives have all been adopted in their turn and examined very carefully, but by 1905, after many years of discussion and experiment, finality had not been reached. Finality is not yet reached, but in that year the discussion took a remarkable, and very unexpected turn. This was due to the appearance of Einstein's special theory of relativity.

Einstein and Relativity.—Einstein suggested that the old problem of the relation of matter and ether had remained unsolved, not by reason of the insufficiency of our knowledge, but because the problem was founded on erroneous assumptions and required an answer in impossible terms. It had always been assumed before, that one system of time and space existed for the whole universe, and that an event always happened at one definite time and at one definite point in

space. In explaining any phenomenon the theorist could make any assumption he chose about the velocity and mass of the bodies involved or the forces acting on them, but he had to keep his hands off time and space. According to Einstein this is not necessary; time and space are merely a mental scaffolding in which we arrange events, and different observers do not require to use the same scaffolding. His theory cuts at the root of many fundamental ideas, and is consequently exceedingly difficult to comprehend. We had always thought of the ether in connection with our one system of time and space; it was at rest in interstellar space, and formed the basis of our whole system of physics. In it in the last resort, all our distances were measured. If the distance between two objects does not depend on the objects only, but on the observer as well, the ether is dethroned from its unique position. Strictly speaking, every observer has an ether of his own. The question then arises as to what medium the light travels in from the sun. Thus the special theory of relativity upset the traditional view of the ether, and this naturally reacted on the position of the wave-theory of light.

In 1915 Einstein carried matters further by the publication of his general theory of relativity. This dealt with gravitational attraction which he regards as due to a property of space, and led to a very slight modification of the Newtonian law. This slight modification explained in a satisfactory manner a long outstanding discrepancy in the motion of the planet Mercury. At the same time the general theory of relativity predicted that a ray of light would be slightly

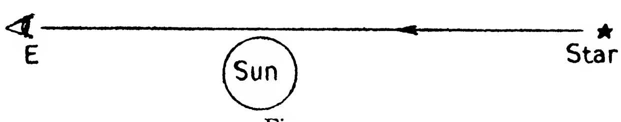


Fig. 20.

deflected by a strong gravitational field. It had previously always been taken for granted, that when a ray of light from a star passed by the edge of the sun to the eye of an observer at E on the earth's surface, it did so undeflected as in Fig. 20. Its path was a straight line, and the observer saw the star

actually where it was. According to Einstein the ray of light was bent as in Fig. 21, and the observer saw the star in the direction S′ and not in its true position at S. A measurable

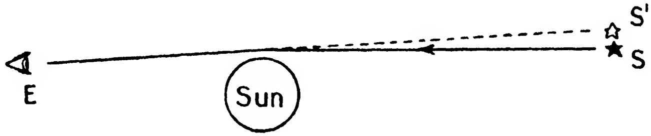


Fig. 21.

effect was to be expected only in the case of the sun's gravitational field which is, of course, much stronger than the earth's; the acceleration of gravity is 27·6 times as great on the sun as on the earth, and a man who weighs 11½ stone on the earth would weigh 2 tons on the sun.

Stars are not visible in the neighbourhood of the sun except at an eclipse, when the light of the latter is hidden. Let a, b and c be the true directions of the stars and S the position of the sun as seen at an eclipse; then according to Einstein's prediction the stars should be seen in the directions A, B and C. They are displaced outwards radially from the sun, and the displacements, aA, bB, cC, are inversely proportional to the distance from the sun's centre. The displacement is extremely small being only 1·75″ at the sun's edge, and during an eclipse we cannot observe close to the sun owing to the light from the corona, so the actual deflections we might expect to observe are considerably less than this. But they are nevertheless within the power of modern instruments. An eclipse of the sun occurred on May 29, 1919, in a part of the sky where there were stars suitable for observing on, so an attempt was made to test the prediction.

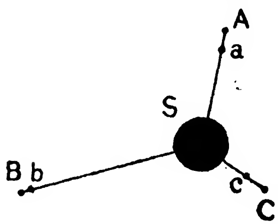


Fig. 22.

Two expeditions were despatched from this country for this purpose, Prof. Eddington and Mr. Cottingham to the island of Principe on the coast of Africa and Dr. Crommelin and Mr. Davidson to Sobral in Brazil. The method employed was to photograph the sky in the neighbourhood of the sun during the eclipse and then photograph the same field at

another time, when the sun had moved to a different part of the sky. The plates were then examined to see whether or not the stars were displaced relatively to the sun during the eclipse. Owing to the war the expeditions were not so well equipped as was desirable, but after the plates were measured and the results reduced, it was found that the Principe expedition got a deflection equivalent to 1·61″ at the sun's edge, and the Sobral expedition 1·98″ with one telescope; with another instrument the Sobral expedition got inconclusive results which were attributed to the sun's heat distorting the cœlostat mirror. The mean of the two results 1·61″ and 1·98″, *i.e.*, 1·795″, is in good agreement with Einstein's prediction.

After the existence of the deflection was proved, various attempts were made to explain it in accordance with the older theories, but none were satisfactory. We must accept the deflection consequently as a fact that does not fit in with the wave theory of light as hitherto understood. Some of the newspapers embellished their accounts of the results of the expeditions with headlines such as "LIGHT CAUGHT BENDING," and suggestions that we might have to return again to the emission theory of Sir Isaac Newton. But this is quite out of the question. The emission theory is dead; great fields of investigation have been opened up, and results established during the past century, to which no one has ever seriously thought of applying the emission theory. It is very difficult to know what will be the upshot. There have been, of course, a very great number of books written "explaining Einstein," but these do not advance the matter, nor have the authors as a rule much independence of judgment. Possibly the soundest attitude is to "wait and see." While Einstein's formulae are mathematically accurate, it is no disparagement of his great work to suggest, that he has not correctly interpreted them. Christopher Columbus died under the impression that it was a new route to the East Indies he had discovered, not America.

Possibly the best criticism of the view, that the discovery makes a *real* difference in our way of regarding time and space

is contained in the following sentences of Thomas Young. He is referring to Laplace's theory of capillarity, but the criticism applies equally well to Einstein.

"It must be confessed that in this country the cultivation of the higher branches of the mathematics and the invention of new methods of calculation cannot be too much recommended to the generality of those who apply themselves to natural philosophy; but it is equally true, on the other hand, that the first mathematicians on the continent have exerted great ingenuity in involving the plainest truths of mechanics in the intricacies of algebraical formulae, and in some instances have even lost sight of the real state of an investigation by attending only to the symbols which they employed for expressing its steps."

Laplace's theory of capillarity on account of its analytic nature is seldom read nowadays, while Thomas Young's own simple and elegant theory figures in every text book of physics. And it is consequently to be inferred that Einstein's work will exert neither a permanent nor a fruitful influence on physical theory, unless a similar way is found of presenting it.

To the physicist who has made some study of the questions involved it is a depressing experience to study the utterances of the philosophers on Einstein or to read a popular discussion on the subject in one of the literary journals. The participants have about as much hope of getting near the gist of the matter as the proverbial blind man in a dark cellar looking for a needle that is not there, though, of course, the interest and energy they devote to the matter is highly creditable. And some of the authors who wish to upset Fresnel's work in order to explain the new deflection of $1{\cdot}75''$ have about as much sense of proportion as the man who would burn down the house to boil his tea-kettle.

The Quantum.—Other difficulties which the wave theory has at present to face are those connected with the quantum. The quantum is a quantity of energy discovered in a theoretical investigation by Prof. Max Planck of Berlin some fifteen years ago, which is specified by the formula

$$h\nu,$$

where h is a constant known as Planck's constant and equal to $6{\cdot}55 \times 10^{-27}$ erg sec, and ν is the frequency of a light wave, *i.e.*, the number of crests that pass per second.

Colour of Light.	Wave-Length.	Fre-quency.	Quantum.
Red ...	·0000650	$4{\cdot}62 \times 10^{14}$	$3{\cdot}02 \times 10^{-12}$ erg
Green ...	·0000536	$5{\cdot}60 \times 10^{14}$	$3{\cdot}67 \times 10^{-12}$,,
Violet ...	·0000442	$6{\cdot}79 \times 10^{14}$	$4{\cdot}45 \times 10^{-12}$,,

The above table gives the value of the quantum worked out for three of the wave-lengths given in the table on p. 25. It increases from the red to the violet end of the spectrum, and there is one particular value of the quantum corresponding to each wave-length.

One of the most puzzling features of modern physics is the way in which the quantum keeps cropping up in different fields of investigation, always in association with light or radiation of the appropriate wave-length. What is the precise connection between them is not known. Opinions vary all the way from the radical view, that there is something seriously wrong with the present theory of light, to the conservative view which is much more widely held, that the theory of light is all right, and that the quantum is the amount of energy liberated or absorbed in some internal change in the atom. The atom, for example, keeps absorbing energy of a particular wave-length until it has accumulated the corresponding quantum; then it changes it into energy of another kind. Or as a result of some unknown internal disturbance a quantum of energy is suddenly changed into light energy and radiated continuously until it is all exhausted.

It would be going too far to give a detailed account of the difficulties associated with the quantum, but the following paragraphs taken from a lecture by Sir Wm. Bragg as reported in *Nature* of May 19th, 1921, may give some idea of their character. Sir Wm. Bragg holds radical views on the subject.

" With the advent of X-rays and radio-activity the process of radiation as a whole is seen to depend in part on the move-

ment of electrons. In the X-ray bulb, to take an example, a stream of electrons, which is truly a corpuscular radiation, strikes a block of metal in the centre of the tube. Energy of radiation is carried outwards through the walls of the tube in the form of X-rays ; that is to say, of wave motion in the ether. When they strike matter, such as the film of a photographic plate, the wave radiation disappears and is replaced by moving electrons which produce all the well known effects ascribed to X-rays. It is probable that this mutual play of waves and electrons is carried throughout the whole realm of radiation, and the ultimate explanation of all optical problems must involve the recognition of corpuscular radiations, at times replacing and being replaced by the waves. Thus once more the corpuscular theory appears again as a working hypothesis.

But in its relation to the wave theory there is one extraordinary and, at present, insoluble problem. It is not known how the energy of the electron in the X-ray bulb is transferred by a wave motion to an electron in the photographic plate or in any other substance on which the X-rays fall. It is as if one dropped a plank into the sea from a height of 100 ft. and found that the spreading ripple was able, after travelling 1,000 miles and becoming infinitesimal in comparison with its original amount, to act upon a wooden ship in such a way that a plank of that ship flew out of its place to a height of 100 ft. How does the energy get from the one place to the other ?

Very lately considerable new information has come to hand regarding the way in which atoms play a part in this extraordinary transference of energy. In many ways the transference of energy suggests the return to Newton's corpuscular theory. But the wave theory is too firmly established to be displaced from the ground that it occupies. We are obliged to use each theory as occasion demands, and to wait for further knowledge as to how it may be possible that both should be true at the same time. Toleration of opinions is a recognised virtue. The curiosity of the present situation is that opposite opinions have to be held and used by the same individual in the faith, that some day their combined truth may be made plain."

CHAPTER III

INVISIBLE RAYS

Now the kinds of radiation
Pass all former expectation.
Wonders press upon our sight,
Heat rays, X-rays, wireless, light,
Ultra-violet. We collect them
In one long extended spectrum.

The Infra-red.—Newton's spectrum was limited by red at the one end and violet at the other. Since his time we have discovered that there is an enormous extent of invisible rays lying beyond the red at the one end and beyond the violet at the other. This discovery has only come bit by bit.

First of all in 1800 Sir. Wm Herschel placed the bulb of a sensitive thermometer on a spectrum, and found that the rays falling on it produced a rise of temperature. Like Newton he used the sun as source and worked with the prism at a hole in a shutter; apparently his spectrum was $2\frac{1}{2}$ feet from the prism. To make sure that the rise of temperature was actually due to the rays falling on it, and not to some other cause, two other thermometers were placed in the shade near the spectrum; it was found they showed no rise in temperature.

The temperature rose 8° Fahrenheit in 10 minutes when the thermometer was placed on the red end of the spectrum, but only 1° F. in 15 minutes when placed on the violet. The intermediate colours gave intermediate values decreasing from the red to the violet. Beyond the violet end of the spectrum there was no effect, but when the thermometer was placed beyond the red end of the spectrum, its temperature rose; $1\frac{1}{2}$ inches beyond the red end the temperature rose $3\frac{1}{8}$° in 10 minutes. The interpretation of this experiment

is, that the sun's rays carry energy with them which is converted into heat, when it falls upon the bulb of the thermometer, that the violet rays have least energy, and that there are rays beyond the red end of the spectrum, invisible heat rays, the infra-red rays as they are called, which carry energy, but do not have any effect upon the eye. Herschel at first drew the correct conclusion from his experiment, but afterwards changed his opinion.

Young found ·0000676 cm. for the wave-length of the red end of the spectrum. Recently heat rays have been measured which have a wave-length of ·0107 cm., or one hundred and sixty times as long as the wave-length of the red end of the spectrum, and from this limit there is an unbroken series all the way to the end of the visible spectrum. The only essential difference between these rays and visible light lies in the value of the wave-length. We have now instruments for recording their presence sensitive enough to detect a rise of one-millionth of a degree. Every source of light gives out invisible heat rays as well as light ; every hot body gives out heat rays. A kettle of boiling water gives out heat rays of wave-length ·0008 cm. The human body gives out heat rays of wave-length about ·0009 cm.

The Ultra-Violet.—When silver chloride is exposed to light it darkens in colour, first assuming a violet tint, and then becoming dark brown or black. The exact chemical nature of the change occurring is not known, but it has been attributed to partial reduction to metallic silver. In 1801 J. W. Ritter found that this property of light did not stop at the violet end of the spectrum, but was greatest beyond the end of the visible spectrum. There were consequently invisible rays beyond the violet end of the spectrum. Herschel introduced the name actinic rays for the rays that produced chemical change. Ten years after Ritter s discovery Thomas Young measured the mean wave-length of the actinic rays in daylight, and found that it was shorter than the mean wave-length of visible light.

The simplest way of showing the action of light on silver chloride is by using ordinary gelatino-chloride printing paper,

or P.O.P. as it is called. If it is held in a very bright spectrum, it may actually be seen darkening under the action of the rays. There is no action in the red or orange, a little in the green, more in the blue, still more in the violet, and most of all just beyond the violet end of the spectrum. The darkening continues into the ultra-violet for a distance equal to the whole length of the blue and the violet.

A much more sensitive way of detecting the presence of ultra-violet rays is by means of the photographic plate. The modern dry plate consists of an emulsion of silver bromide in gelatine, which has been poured while warm on to a large glass plate and allowed to set. The glass plate is then cut into smaller sizes. The light produces no visible action on the plate, until the developer is poured over it. Then the particles of silver on which the light was incident are reduced to black metallic silver. After development the plate is "fixed" by immersion in a solution of hyposulphite of soda, which dissolves away all the sensitive particles on which the light has not acted. It is then washed and dried. As the bright parts of the image, those on which most light falls, come out black on the plate and the dark parts come out light, the picture is said to be a negative. By placing it in contact with sensitive paper and allowing light to act through the negative on the paper, an image called a positive is produced on the paper. In this image the light and shade are correctly rendered; it is the picture wanted, the negative being only an intermediate step.

By means of the photographic plate the spectrum has been traced a long way into the ultra-violet. Glass absorbs all the ultra-violet light with a wave-length shorter than ·000033 cm., so if we wish to go further into the ultra-violet, a prism of quartz must be used. Sunlight ceases about ·000030 cm., the earth's atmosphere absorbing all the radiations beyond this limit. To produce a spectrum beyond this limit an electric spark or electric arc must be used as source of light. The gelatine of the plate begins to absorb at ·000025 cm, and at ·000022 cm. the light does not penetrate more than ·002 cm. into the gelatine film, *i.e.*, to a greater distance than about

one-tenth of its thickness; beyond this region plates without gelatine must be used. Quartz ceases to transmit at ·000018 cm. Beyond this a fluorite prism must be used. The air of the atmosphere next gives trouble; a layer of air one-twenty-fifth of an inch thick at normal atmospheric pressure absorbs entirely all the rays below ·000017 cm. By enclosing the apparatus in a vacuum first Schumann and then Lyman carried the investigation further into the ultra-violet; at present the limiting point reached is about ·00000202 cm. This was attained by Prof. Millikan of Chicago in 1920 with a vacuum grating spectrograph. It represents a radiation with a wave-length about one-thirtieth of the value for yellow light.

Invisible Rays in War.—The possibilities of invisible rays have always appealed to the imagination of inventors and cranks, and, as any one connected with the government departments dealing with inventions knows, there were many mad schemes proposed for using them during the war. The infra-red rays or heat rays have been on the whole the more popular. They have a quite respectable antiquity. Archimedes, the most celebrated mathematician of ancient times, is said to have set the Roman fleet on fire, and destroyed it at the siege of Syracuse in 212 B.C. by concentrating the heat rays of the sun upon it with concave mirrors. The fleet was then one bow shot distant from the walls. But the story is either a pure invention or arose from a misunderstanding. It is not mentioned by Polybius, who was almost a contemporary of Archimedes, and who has given a detailed account of the siege. Only in the second century after Christ do we first hear that Archimedes destroyed the Roman fleet by fire, and then mirrors are not mentioned; that part of the story dates only from the fourth century of our era.

Napier of Merchiston (1550–1617), who discovered logarithms, also proposed to destroy an enemy's ships by heat rays, as part of a general scheme "for defence of this Iland" and the rendering of Britain safe from all her enemies. The document detailing the scheme is in Napier's own hand, and is preserved in Lambeth Palace.

And H. G. Wells in *The War of the Worlds* has let his imagination play upon heat rays in a very unfettered manner, and easily outdistances both Napier and Archimedes. The heat ray was the Martian's chief weapon of war. It was a noiseless and blinding flash of light which carried miles. Pine trees burst into flames, as the shaft of heat passed over them, and every dry furze bush became with one dull thud a mass of flames. It blotted out all living things, and in its track the dark ground smoked and crackled.

Needless to say this is far beyond the bounds of possibility. The flame-throwers used by the Germans in the war, which were not heat rays at all, but jets of burning oil, did not carry far, and were used rather for their effect upon the enemy's morale than for the destruction they did. One pattern consisted of a ring-shaped oil container surrounding a spherical vessel containing compressed nitrogen, which was used to expel the oil, and a flexible tube of rubber and canvas carrying the jet; the whole was arranged to be carried on the back.

The most celebrated burning mirrors in history were quite moderate affairs. These were made by Tchirnhausen. In 1687 he made a mirror of copper of three ells diameter and two feet focal length. It kindled wood, boiled water, melted tin which was three inches thick, and made a hole in a coin in five or six minutes. But when it was used to concentrate the moon's rays, not the slightest quantity of heat was produced. Tchirnhausen also made burning glasses. His largest one was 33 inches in diameter, and had a focal length of 12 feet. He used it in combination with a condenser, and amused himself by boiling fish and crabs in water with it. One of his burning glasses was also used in a celebrated experiment at Florence to burn up diamonds; the fact that diamonds are combustible, was then demonstrated for the first time. The Emperor Francis I showed later at Vienna, in 1751, on a somewhat expensive scale, that diamonds could be completely burned up in an oven. He was not, however, actuated by scientific motives, but was merely trying by a "secret process" to melt little diamonds together into one big one.

Numerous suggestions have been made to destroy airships

or explode an enemy's ammunition dump by the use of actinic rays in war time, but the authors have never explained how it was to be done. The maddest proposal I have heard of in connection with ultra-violet rays was to use them for obtaining secret plans of an enemy's fortifications. An airship was to be employed on a very dark night. The night was to be so dark that the enemy were not to see the airship. The crew of the airship were to direct invisible rays down on the enemy's position and take photographs of that position by means of these invisible rays. One fundamental weakness of the scheme, even if the other conditions were realised, is that the invisible rays would be far too weak for taking photographs; they would necessitate exposures of hundreds of years.

Secret Signalling.—One disadvantage of wireless telegraphy is that anyone can " listen in " and pick up the signals, and even if they are sent in a code, it is always possible for an enemy to jam them by simultaneously sending much louder signals of his own. So when telegraph or telephone wires are not available, it has been proposed to signal by invisible rays. This would be convenient for sending a message through an enemy's lines and for the use of spies in general, though I do not think it figured in any of the spy novels produced to meet the public demand during the war.

The difficulty about using light signals, namely, that the intermittent interruption involved in using the Morse code is visible to everyone within the field of view, can be got over by using a very light yellow gelatine film instead of a shutter in front of the lamp. A yellow similar to the filter employed in photography for weakening the violet end of the spectrum is used. The alteration produced in the colour of the light by bringing the film down in front of it is so slight as to escape notice, and persons for whom the message is not intended think the light is uniform in intensity. At the receiving station, however, they use a deep blue filter which cuts out all light except the violet end of the spectrum; when observed through this film the interposition of the yellow film produces a very great change in the intensity of the light, and the signals are

easily visible. The combination of yellow and blue film placed together is almost opaque.

Another method of using light signals secretly is to change the condition of the light, without altering its intensity, by polarising it and depolarising it. This is done by passing it first through a nicol prism and then using as shutter a thin sheet of mica known as a quarter wave plate. The light emitted is consequently either plane polarised or circularly polarised. It is viewed at the receiving station through another nicol; when the shutter is down the light is visible, when it is up it is either completely or almost completely extinguished. But when it is viewed directly, its intensity remains unaltered. Both the above methods were experimented with in Britain, Germany, Italy, and America during the war, and probably in other countries as well.

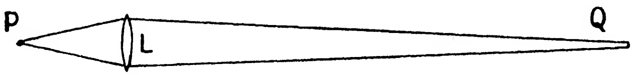


Fig. 23.

The simplest and most effective method of signalling secretly by means of rays is simply to limit the aperture of the beam. A naked light is visible in all directions, but if it is enclosed and placed at the focus of a lens, it emits light only in one direction. Suppose, for instance, the lamp is a small incandescent bulb with a single straight filament taking $1\frac{1}{4}$ volts and giving $\frac{1}{4}$ candle, and the lens is an achromatic telescope object glass with a focal length of two feet. P in Fig. 23 is a section of the filament at right angles to its length, and L is a section of the lens. The rays issuing from P fall on the lens, and are brought to a focus at some point Q. The diameter of the image at Q bears the same ratio to the diameter of the object as the distance LQ bears to PL. Now the diameter of the filament of a wire filament lamp is very small, being about ·003 cm. Consequently at a distance of one mile the image at Q should have a breadth of $\frac{5280}{2} \times \cdot 003 = 8$ cm., or about 3 inches. Thus the beam is extraordinarily narrow, 3 inches at the one end and 2 inches, *i.e.*, the diameter of the

object glass, at the other. Only if the observer has his eye inside the beam, will he see the light.

The difficulty in using a filament with a single lens as shown in Fig. 23 lies in sighting it on the exact position at the receiving station, where the signals are to be read. This difficulty can be got over, if a telescope is employed instead of a single lens, and the filament of the lamp used as crosswire of the telescope. Fig. 24 shows how the lamp should be fitted. The bulb of the lamp should be of clear glass. If the telescope is focussed on a distant object, say the window of a house, the signaller looking through the telescope sees the bulb in the

Fig. 24.

centre of the field. The glass of the bulb impairs definition only very slightly, the house is seen quite distinctly through the bulb, and the telescope can be pointed so as to make the image of the filament fall on the window. The signaller then removes his eye, and by means of a tapping key causes the filament to light up. The signals are visible only at the window on which the image of the filament falls. In actual practice the beam is not quite so narrow as it should be theoretically ; with a Mark IV. signalling telescope I have found it one foot in width at one mile and five feet at five miles. At five miles anyone outside the five feet saw nothing, but within the beam the light was as bright as a lighthouse. The actual size of the lamp or amount of power used is quite immaterial. It is only the intrinsic brilliancy of the particular part of the filament, the image of which falls on the observer, that counts. And by using a 1¼ volt filament and over-running it up to 2 volts, the intrinsic brilliancy can be made very great. A larger lamp, a 200 candlepower half-watt lamp, for example, would not increase the range in the slightest.

It is remarkable how far one can signal with a glow lamp, if a lens is used with it. A student of my acquaintance signalled from Scotland to Ireland, a distance of 22 miles, by

means of a pocket flash lamp and a lens. The lens was, I think, a spectacle lens; in any case it was not a good one. The sighting was done by focussing an image of part of the filament on a distant wall. Attempts were made every evening for a week, but on only one evening was success attained. There is no doubt the apparatus should carry the distance, but with an arrangement of this sort the sighting would be very difficult indeed.

Wireless Telegraphy.—If we move far into the infra-red spectrum, the rays become weak and finally cease altogether. The longest heat waves measured have a wave-length of ·0107 cm. At this point the dark heat spectrum stops. But after a short interval it starts again under a new guise; the waves used in wireless telegraphy, the electromagnetic waves, are of precisely the same nature as light waves, having exactly the same velocity and differing from light only in having a longer wave-length. Electromagnetic waves have been produced with a wave-length as short as ·16 cm. and as long as hundreds of kilometres. The wave-length generally used in wireless telegraphy at high-power, long-range stations is about 10 kilometres or 10,000 metres. All commercial and coast stations are equipped so as to transmit on wave-lengths of 600 and 300 metres, the intention being that communication, if jammed on the one, may possibly be established on the other. The S.O.S. is always sent out on the 600 metre wave, as the receiving apparatus in ships is normally adjusted for this wave-length.

Wireless waves are able to pass readily through bodies which are opaque to light and heat waves, except when the latter conduct electricity; then electric currents are produced, and some of the energy is lost. Buildings present no obstacle to them. They can be transmitted to much greater distances by night than by day. Sometimes a message is jammed by a disturbance in the atmosphere itself; these disturbances called "strays" or "atmospherics" are especially strong in the neighbourhood of thunder storms.

X-Rays.—We have seen that at the end of the infra-red

spectrum there is a gap, namely from ·0107 cm. to ·16 cm. and then the electromagnetic waves start. In the same way at the extreme end of the ultra-violet there is also a gap on the other side of which the X-ray spectra are situated. X-rays differ only from visible light in having an extremely short wave-length. This was not known however for a long time, and their nature was a mystery; hence the designation X-rays.

They were discovered by Prof. W. K. Röntgen at Würzburg, in 1895. When they fall on a fluorescent screen of barium platino-cyanide, they cause it to light up, and they also act on a photographic plate. It was the former property that caused their discovery; an electric discharge was passing in a tube which was completely covered with thick black paper. To his surprise Röntgen noticed that a fluorescent screen three yards away shone brightly. There was no apparent cause for this. When objects were placed between the tube and the screen, shadows were cast, hence the effect was due to some mysterious radiation proceeding from the tube. This radiation had the property of passing through thick black paper, a thing that ultra-violet light could not do, hence it could not be ultra-violet light; further investigation revealed the fact that it was a radiation of an entirely new type, and that it possessed many wonderful properties.

X-rays travel in straight lines. They pass through a prism without deviation, and they are not acted on by lenses. They have the striking property of penetrating media that are opaque to ordinary light. They pass through paper, cloth, and aluminium, but are stopped by the more dense metals, especially lead. Flesh is transparent to them but the bones are opaque, and by their aid we can see the bones through the flesh. They have thus an important application in surgery. If a purse with coins in it is held up between the source of the X-rays and the fluorescent screen, in the shadow on the screen the coins are visible through the purse; if a wooden box containing brass weights is held up, the weights are visible through the box.

Arrangement for Demonstrating X-Rays.—P indicates the wires leading in the primary current; the latter comes from a battery of five storage cells. C is the commutator of the

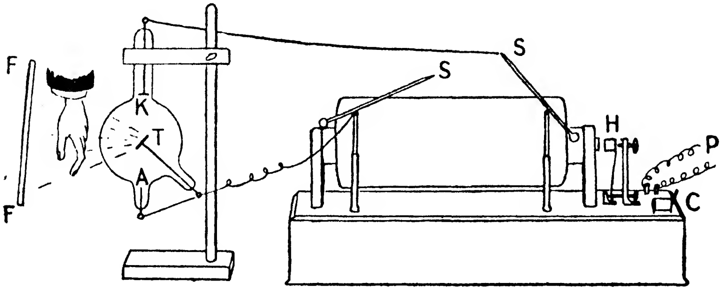


Fig. 25.

induction coil, H the hammer-interrupter, and S the terminals of its secondary. The X-ray bulb is supported in a wooden retort stand. The wire from the one terminal is attached to its kathode K, and the wire from the other terminal to its anti-kathode T and anode A. The kathode rays impinge on T causing X-rays to diverge from the latter. These X-rays pass through the glass of the bulb and the hand, casting a shadow of the bones of the latter on the fluorescent screen FF. This shadow is viewed from the other side of the screen. A radiograph, or photograph by means of the X-rays can be obtained by substituting a photographic plate for the screen FF; such a radiograph is shown on Plate I.

Nature of X-rays.—X-rays are not reflected or refracted by a polished glass surface, and for many years this was very difficult to explain. But the explanation, when it came, was a most convincing one. A surface reflects and refracts light only if the inequalities in it are small in comparison with the wave-length of the light. The very process of polishing a a mirror consists in removing the inequalities in its surface. Now if the wave-length of X-rays is $\frac{1}{6000}$ of the wave-length of yellow light, it is much the same size as the diameters of the molecules themselves; consequently it is impossible for us by any means whatever to prepare an artificial surface smooth enough to reflect and refract waves of this length. We had

been using the wrong metaphor; when X-rays fall on a substance, the phenomenon is not analogous to a train of sea waves being reflected from a concrete breakwater, but to the same train sweeping through the wooden piles below a pier. In the latter case there is no general reflection from the pier as a whole, but when a crest reaches a pile, the latter sends out weak secondary crests of its own. Each pile acts as an independent centre and scatters some of the energy of the incident wave. Now in an amorphous substance like glass the molecules are arranged irregularly, so the secondary waves should annul one another. In a crystal, however, the molecules are arranged regularly; Fig. 26 for example, represents a NaCl crystal, a crystal of rock salt, with the atoms shown in position, the black spheres being the sodium atoms and the white spheres the chlorine atoms. It consequently occurred to Prof. M. Laue at Munich in 1912 that if a thin pencil of X-rays fell on a crystal, each atom would act as a centre of secondary waves, and that owing to the regularity of the structure the crests of these secondary waves would superimpose, and they would consequently reinforce one another in particular directions. The idea was tested by placing a photographic plate behind a zinc blende crystal. When the plate was developed, there appeared a central black spot surrounded by a number of fainter spots. The black spot was formed by the direct pencil, and the fainter spots by the reinforcement of the secondary waves.

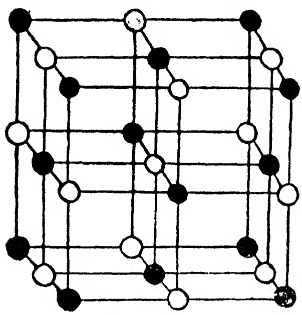


Fig. 26.

Thus Laue's idea was brilliantly vindicated. X-rays had neither been reflected by mirrors, nor refracted by lenses, simply because their wave-length was so small, of the same order of magnitude as the distances between the atoms. Consequently in comparison with it the structure of the reflecting or refracting body could no longer be regarded as continuous.

Gamma Rays.—Radium emits three types of rays, alpha rays, beta rays, and gamma rays. The beta rays consist of electrons projected with velocities varying from 60,000 to 180,000 miles per second. The alpha rays are positively charged atoms of helium. The gamma rays are regarded simply as X-rays of a very short wave-length ; the wave-lengths of the whole series of X-rays—the types described as hard, medium, and soft, together with the gamma rays of radium—range from about 5 to ·005 A.U.

The Complete Spectrum.—We have seen in the preceding pages, that the original spectrum of Newton has grown an enormous distance at both ends, and that we now have at our disposal a series of radiations having the most widely different properties as regards their action on matter that it is possible to imagine, but differing essentially from one another only in the length of the wave. Fig. 27 represents their relation schematically. Some idea of the relative magnitude of the wave-lengths may be obtained from the following comparison : if the gamma-ray waves are a fraction of an inch long, the X-ray waves are about one foot ; the ultra-violet waves extend from 55 yards to $2/3$ of a mile, the visible from $^2/_3$ to $1\frac{1}{3}$ miles, the infra-red to 180 miles, and the wireless waves from 3000 miles to the distance of the nearest star.

Fig. 27.

The Selenium Cell.—The selenium cell is an instrument for detecting the presence of light rays which has recently found many practical applications. Selenium is an element very similar in its chemical properties to sulphur. Metallic selenium conducts electricity, and has the remarkable property that its conductivity is increased when light falls on it ; the conductivity of a thin layer of selenium when exposed to diffuse daylight is about twice as great as when it is in the dark. The conductivity varies with the varying intensity of the light, and the change occurs almost instantaneously. When the light is removed, the drop in conductivity occurs

very rapidly. According to the modern view, when an electric current flows along a wire, there is a procession of small negative charges of electricity, called electrons, along the wire. The electrons are much smaller than atoms. The electrons which convey the electric current are called " free " or " conductivity electrons " to distinguish them from other electrons, the " bound electrons," which remain inside the atom. When the rays of light fall upon the selenium atoms, electrons are ejected from them. Thus the number of free electrons is increased, and consequently the conductivity of the metal is increased. But when the light rays are removed, these electrons go back to the parent atom.

The sensitiveness of selenium to light was discovered fifty years ago, but remained for a long time of no practical use, as the first selenium cells, as they are called, were not reliable. One of the best known modern cells was made by Fournier d'Albe in 1911. It consists of a tablet of porcelain, which is covered with graphite and then engraved in fine grooves from side to side. The whole is finally coated with molten selenium.

If an ordinary telephone receiver is connected in series with a selenium cell and an electric battery, a current will pass through the telephone. No sound will be heard in the telephone as long as the current is steady, but if light falls upon the cell its conductivity alters, and the current increases; this makes a sound in the telephone. The telephone receiver is essentially an instrument for converting changes of electric current into sounds. By means of the telephone you can hear the light falling upon the selenium plate. If flashes of light are thrown on to the cell at a uniform rate, for example at 256 per second, a musical note, in this case middle C of the piano, is heard.

The Optical Telephone.—In an ordinary telephone the transmitter and receiver are connected by wires, and an alternating conduction current is transmitted along these wires. In ordinary wireless telephony, as the name implies, there are no wires; the transmitter is connected to one aerial and the receiver to another; the message passes between these aerials as electromagnetic waves in the ether. But in another

kind of wireless telephony which has been developed by Dr. A. O. Rankine of the Imperial College of Science and Technology, the message is transmitted by a fluctuating beam of light, a beam of light which fluctuates so rapidly that, owing to persistence of vision, it appears to the observer as perfectly steady in intensity.

In Dr. Rankine's method the message is spoken into a gramophone reproducer, into a horn at the narrow end of which is a diaphragm ; the horn collects the sound wave, directs it on to the diaphragm, and the latter is thrown into vibration. It is connected by a lever to a very light concave mirror. A powerful beam of light falls on this mirror, and then falls upon a grid. When the diaphragm is at rest, the light gets through the grid ; when it is displaced, the mirror is inclined, and the beam stopped. The details of the arrangement are particularly ingenious but cannot be described here. At the receiving station the beam is collected by a lens, and focussed on to a selenium cell which is connected in circuit with a telephone receiver and a battery. If, for example, middle C is sung into the transmitter, the diaphragm, and consequently the mirror, vibrates 256 times a second, the beam is obstructed 256 times a second, 256 flashes of light per second fall upon the selenium cell, and the note C is heard in the telephone. The vibrations impressed on the diaphragm by ordinary speech are transmitted in the same way.

The arrangement was tried at a distance of about two miles and found to work very satisfactorily, but of course is open to the objection common to all methods of optical signalling, that the beam of light does not get through in misty or foggy weather.

Speaking Films.—In making a phonograph record the words are spoken into a horn ; the sound waves which constitute these words cause a thin glass disc at the end of the horn to vibrate, and the vibrations of the disc cause a chisel-shaped sapphire point to move up and down, cutting a groove of varying depth in the wax, which is rotating below the point at a uniform speed. To reproduce the sound a slightly different arrangement is fitted, consisting of a smooth sapphire point

which passes along the indentation produced by the recording point. This sets a thin glass disc at the end of the horn into vibration, and the vibration of the glass reproduces the original waves. The records made by an amateur in wax do not last very well. The records sold in the shops are made from moulds, and are in a much harder material. In gramaphone records the grooves are of varying width, not of varying depth, and the needle moves from side to side, not up and down.

Dr. Rankine has used his apparatus to record sound waves, not by grooves of varying depth or width in a hard material, but by a band of varying density in a photographic film. Fig. 28 represents the arrangement. The words are spoken

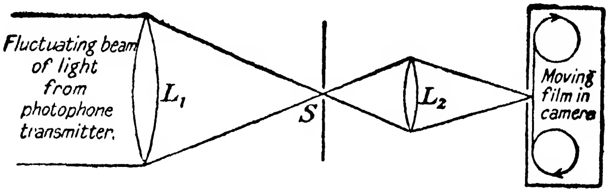


Fig. 28.

(*From Proceedings of The Physical Society of London.*)

into the transmitter of the optical telephone, but the beam of light instead of being sent two miles is received at once by the lens L_1, and focussed on a slit S. An image of this slit is focussed on a moving film in a camera by means of lens L_2. As the light fluctuates in intensity, the density of the image formed on the film varies. Plate III represents positives made from films exposed in this manner. In Example I, as might have been expected, only the fundamental frequency is indicated ; in Example II the first overtone, frequency 1040, is seen superimposed on the fundamental. Examples IIIa and IIIb represent respectively the beginnings of the words " five " and " one." The complete record of each of these words has on the scale shown a length of 40 cm. Example IV is the record of that part of the word " five," where the " i " sound changes to the " v " sound ; " i " is to the left, " v " to the right, and the change of character is shown fairly well.

An interesting feature of the records is that they provide accurate instantaneous pictures of the sound waves. The latter are, of course, longitudinal, and consist of changes of density in the air through which they are propagated ; changes in density are represented here by the changes in density of the photographic film.

To reproduce the sounds from the films the arrangement of Fig. 29 is employed. An electric arc is focussed on the horizontal slit S, and the lens L produces an image of the slit on the film at F. The quantity of light transmitted through F varies with the density of the film, and hence the conductivity of the cell varies with the density of the film. This in its turn produces vibrations in the electric current, and these are converted into sound waves by the telephone receiver.

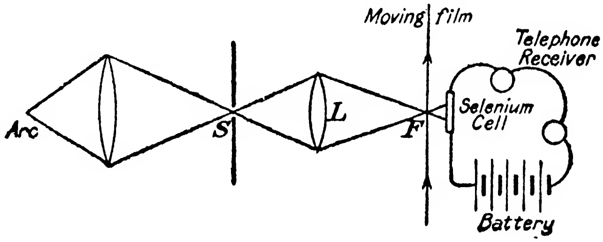
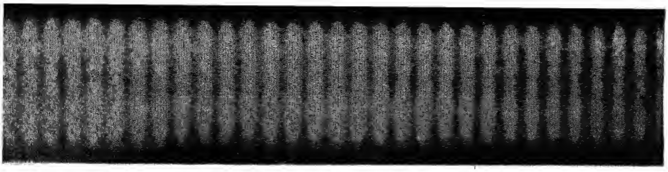


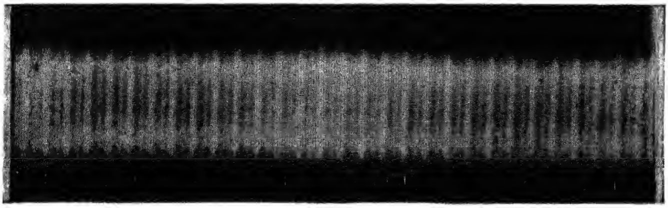
Fig. 29.

(From the Proceedings of The Physical Society of London.)

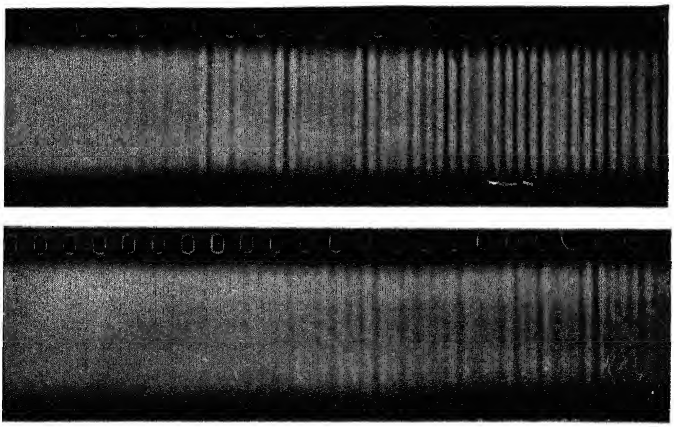
Gramaphones have been used in conjunction with cinematographs, but not very successfully. For with this arrangement we have two separate mechanisms, one for running the film and the other for turning the record, and it is difficult to keep them in unison. The length of the film is gradually but inevitably shortened by the repairing of breakages. Consequently there is difficulty in getting the words uttered by the gramaphone to synchronise with the movements of the lips in the picture. If the sound waves were recorded on the same film as the pictures, side by side with the latter, synchronisation would be automatic. Experiments are proceeding at present on these lines, and there have been reports in the newspapers of a successful demonstration of talking pictures in Sweden for which the sound record is made



Example I. Tuning Fork, Frequency 512 per second.



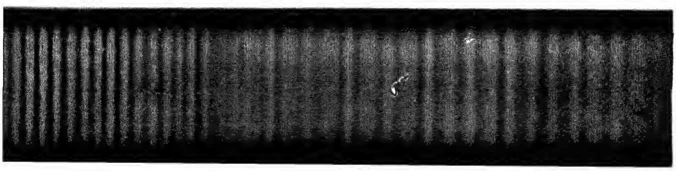
Example II. Open Organ Pipe. Fundamental Frequency 520 per second.



a)

(b)

Example III. (*a*) Beginning of word "Five."
,, III. (*b*) Beginning of word "One."



Example IV. Towards the end of the word "Five."

From Dr. Rankine's paper. By permission of the Physical Society of London.

PLATE III.

on a film, but details are not available. There seems little doubt that the method is practicable, if it is worth while. In a film representation of *Hamlet*, for example, it is no doubt desirable that the hero should speak his part, but it seems almost inevitable under present conditions, that he would speak it with an American accent.

The Optophone. Making the Blind See.—Hitherto the only method by which the blind might read has been by feeling the letters printed in the Braille or other systems in specially embossed books. These books are very expensive and bulky. By this method the sense of touch is made to take the place of the missing sense of sight. The optophone is an instrument by means of which the sense of hearing is made to take the place of the missing sense of sight, and which enables the blind man to read ordinary printed matter such as books and newspapers. By means of it he hears letters as combinations of musical notes. Thus " w " is *me ray doh ray me ray doh ray me,* singly one after the other, " i " is the chord *me ray doh,* and so on. He thus hears his way along the line of type, and learns rapidly to distinguish the " tunes " corresponding to the common words in the same way as a telegraph operator interprets a succession of clicks on the Morse code. Speeds of twenty-five words per minute have been attained.

The optophone was invented by Dr. Fournier d'Albe of London in 1912, and greatly improved and developed and put upon the market by Messrs. Barr and Stroud, Glasgow, who are well known as the makers of the celebrated range finders. In size it is a little larger than a portable typewriter. It has a glass plate on the top of which the open book rests face downwards. Five little spots of light in a row, known as the scala, pass along the printed line. Each spot vibrates in intensity at a different rate. The three middle spots catch the small letters, the lowest spot letters with tails below the line, and the highest spot letters with heads above the line, as shown in Fig. 30. The light diffusely reflected from the five spots is received by a selenium cell connected with a telephone receiver; owing to the vibrations in intensity the light reflected from the spots sounds *soh doh ray me soh*

respectively in the receiver, the one *soh* being an octave higher than the other. The telephone ought to sound when light is reflected from the white paper, but by balancing the current through the cell against another current through a similar cell which is exposed to the five spots directly, the telephone is made to sound when the spots fall on the inked part of the paper. Thus in the example given (Fig. 30) we have silence until the top spot reaches the head of the "T"; then *soh* sounds. When the stem of the "T" is reached, *doh*, *ray*, *me* and *soh* sound simultaneously. Next we have *soh* alone and then silence. "y" starts with low *soh* and *me* simultaneously, and so on. The instrument has arrangements for adjusting the width of the scala to the size of the type, changing from line to line, etc., but these cannot be described here. A picture of the instrument is given on Plate IV.

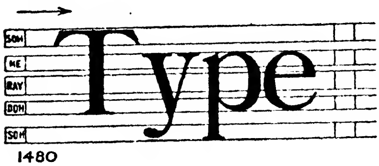


Fig. 30.

(*Barr & Stroud Limited.*)

CHAPTER IV

APPLICATIONS TO THE STRUCTURE OF ATOMS AND STARS

In this chapter we shall give a brief account of the most important recent work on Light and the Spectrum. It is concerned with the infinitely small and the infinitely great, the constitution of the atoms and of the stars.

Atoms and Electrons.—The chemical student of twenty years ago thought of the atoms as smooth, hard, round spheres. They had different sizes and different weights; the atom of hydrogen was small and light, the atom of lead big and heavy. The molecule of a compound substance like common salt consisted of two atoms, a chlorine atom and a sodium atom, stuck together. The atoms of each element were all exactly alike. They had existed unchanged and unchangeable from the Creation, and chemical analysis told us all that was to be known about the constitution of a body. Of course the student was not taught all this, but it was the mental picture he formed unconsciously as a result of his course of study. There were older men who knew how much of the current belief was hypothetical, but they realised it was necessary in teaching the subject to start with concrete unqualified statements.

The relative weights of the atoms of the different elements had been determined. If the weight of the oxygen atom is taken as 16, the weight of the lightest atom, hydrogen, is 1·008, and of the heaviest atom, uranium, is 238·2. If all the atoms are arranged in order of their atomic weights, it is found that certain chemical properties recur at definite intervals. Thus the alkali metals, lithium and sodium, which are

very similar in their properties, are eight elements apart in the series, as are also oxygen and sulphur, another pair of closely related elements. This periodic recurrence of the same properties, discovered by Newlands and Mendelejeff, was a standing challenge to the chemist. If the atom was elementary and not indivisible, then the periodical recurrence of chemical properties could not be explained. So there were chemical reasons against the hypothesis of the indivisible atom. The attack on it, however, did not come from this side but from the phenomena of radioactivity. It was found that there were differences existing too subtle for chemical analysis to detect, and that certain "elements" such as radium were actually disintegrating and breaking up in the laboratory, changing into other "elements" and at the same time liberating great quantities of energy.

It was shown by J. J. Thomson and his school that all atoms contain a common constituent, the electron, a particle with a definite and constant charge of negative electricity and a weight about $\frac{1}{1800}$ the weight of a hydrogen atom. Different lines of investigation led to the result that the whole weight of the atom was not due to the electrons, but that the number of electrons in the atom was roughly about half the atomic weight. It was also shown by Rutherford, that nearly all the weight of the atom must be concentrated in a core at its centre.

Modern Spectroscopy.—In the sixties of last century when the new method of spectrum analysis was in the first tide of its success, interest centred chiefly in the discovery of new elements and in determining the constitution of bodies by the examination of their spectra. Then Kirchhoff and Bunsen discovered caesium and rubidium, Crookes discovered thallium, and Lockyer and Frankland discovered helium all about the same time by means of their spectra, and by the comparison of the spectra of the sun and stars with the spectra of certain terrestrial elements the existence of these elements was proved in the sun and the stars. In all these investigations the existence of the atom as an indivisible unit was taken for granted. Nowadays the centre of interest has shifted;

spectroscopy is studied not so much with the view of explaining matter in terms of atoms, but as a means to getting at the structure of the atom itself. The examination of spectra in the visible region and near ultra-violet which went on for so many years, was not fruitful of results in this respect. But after the discovery by Laue and his collaborators in 1912, that X-rays were a form of light differing only from ordinary light in the extreme smallness of the wave-length, the study of X-ray spectra was taken up, and in the hands of H. G. J. Moseley led to results of the highest importance.

Moseley started this work as a research student in Rutherford's laboratory at Manchester where he had taken his degree, and continued it at Oxford. He answered the call to arms at the beginning of the war, and was killed in 1915 at the age of 28 during the Suvla Bay landing in Gallipoli, while serving as Signals Officer to an infantry brigade, a tragic end to a promising career. His work on X-ray spectra is described in two papers in the *Philosophical Magazine* of December, 1913, and April, 1914, which will always remain of fundamental importance in this subject.

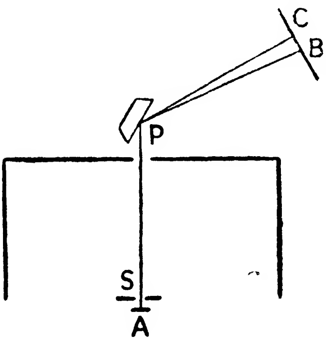


Fig. 31.

The X-ray Spectrometer.—Moseley's work was done with the X-ray spectrometer. This instrument differs from the instruments used for producing visible spectra in having no lenses and having a thin crystal plate instead of a prism. Lenses, as has been previously mentioned, are of no use for focussing X-rays; the latter pass through lenses undeviated. Fig. 31 shows the essentials of Moseley's arrangement; A is the source of the X-rays, the anti-kathode in an X-ray tube fitted with a mechanical arrangement by which the material of the anti-kathode might be altered easily. The X-rays diverging from A passed through a fine slit in a platinum plate S, about $\frac{1}{5}$ mm. wide, then through an aluminium

window; the rest of the radiation was cut off by a lead box which surrounded the tube. They next fell on the cleavage face of a crystal of potassium ferro-cyanide at P. Now the atoms in a crystal are arranged in planes parallel to the cleavage face. In Fig. 32 an X-ray is shown falling in succession on atoms in three separate planes; each atom reflects some of the incident energy as shown in the figure. In general the reflected rays interfere with one another; crest falls upon trough and trough upon crest, so there is no visible result. But if the crest of the rays reflected from the one plane falls upon the crests of the rays reflected from the others, then the rays reinforce one another in this particular direction. In Fig. 31 the incident pencil is supposed to contain two separate wave-lengths; consequently we obtain reinforcement in the two directions PB and PC, and two reflected rays are formed; these produce two black lines on a photographic plate at CB. Usually more than two black lines are produced on the plate. These lines form a spectrum exactly analogous to the line spectrum of mercury shown facing p. 6, only they have very much shorter wave-lengths. They are not strong enough to show on a fluorescent screen and can only be photographed.

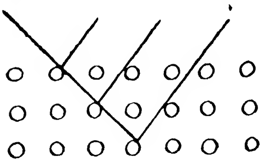


Fig. 32.

The exposure took about five minutes. Some of the radiations were absorbed by air; consequently this part of the work had to be done in a vacuum.

Moseley's Results.—The striking feature of Moseley's results is their simplicity and regularity; spectra obtained in the visible and ultra-violet regions are very complicated, and although regularities have been detected in their structure, these are not very apparent. It is quite otherwise in the X-ray region; every element has a spectrum of the same type, containing two series of lines, the K series and the L series. The L series has the longer wave-lengths, and consists of five lines; the K series has four lines.

Fig. 33 is a drawing exhibiting some of the results. The

scale at the foot gives wave-lengths in A.U., *i.e.*, the shortest wave-length on the scale is about $\frac{1}{6000}$ of the wave-length of

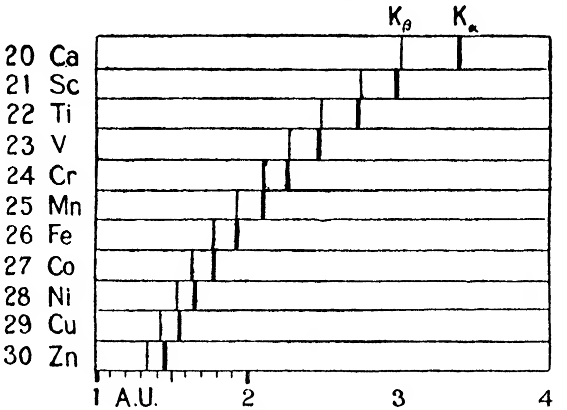


Fig. 33.

yellow light. At the side are the symbols for calcium and zinc and the nine elements with atomic weights between calcium to zinc arranged, except for the transposition of cobalt and nickel, in the order of increasing atomic weight; beside the symbol is the number of the element, counting from hydrogen as 1. Opposite the symbol of each element are two vertical lines showing the positions of the K_α and K_β lines for this element, *i.e.*, part of the X-ray spectrum of the element.

It will be noticed that the spectra gradually pass into one another, and if a certain spectrum were wanting, it would be possible to predict its nature by fitting it in between the one above and the one below it. The numbers on the left are referred to as the atomic numbers of the elements. In order to make the results for cobalt and nickel fit in with the rest it was found necessary to invert the order of the atomic weights; cobalt is 27 and nickel 28, while the atomic weights are 59·0 and 58·7 respectively. It was also necessary to invert the order of potassium and argon. In both cases it has been found that the chemical properties agree better with the spectroscopic evidence than with the order of the atomic weights. It was also necessary to assume that certain

elements had not yet been discovered, for example, those with numbers 43 and 75. Uranium has the highest of all atomic numbers, namely 92.

Thus spectroscopic evidence has fixed the number of the chemical elements, and taken in conjunction with other evidence has made it practically certain, that the atomic number gives the number of the electrons in the atom. It also shows, that with reference to the constitution and properties of the atom atomic number is a much more important characteristic than atomic weight.

The Structure of the Atom.—The electrons constitute only a very small part of the weight of an atom. As has already been mentioned, according to the view of Rutherford which is generally accepted at present, each atom has a nucleus or core of extremely small dimensions which carries practically the whole of its mass, and which has a positive charge sufficient to neutralise the negative charges of the electrons, and hold them in position. The electrons surround the nucleus at distances great in comparison with the dimensions of the latter.

The question arises as to the nature of the nucleus. If we consider the atomic weights of the first 18 elements, we find they are 1·008, 3·99, 6·94, 9·1, 11·0, 12·0, 14·01, 16·00, 19·0, 20·2, 23·00, 24·32, 27·1, 28·3, 31·0, 32·07, 35·46, 39·9. Only four have other figures than ·9, ·0, or ·1 in the first decimal place. If the numbers in the first decimal place were distributed according to chance, since there are ten digits, the proportion should be $\frac{7}{10}$ of 18, *i.e.*, 12 instead of four. The atomic weights of these elements are thus nearly multiples of the atomic weight of hydrogen; consequently it appears that the nuclei of these elements may be built up of hydrogen nuclei as units. The agreement is not so good as we go higher up in the table, owing possibly to the cumulative effect of small deviations. But the view is strengthened by the fact, that the alpha particles ejected by the radioactive elements have a weight four times the weight of the hydrogen atom and two positive charges.

The nature of the nucleus and the number of electrons in

the atom being decided, the question arises as to the position of the electrons with reference to the nucleus. According to one view they revolve about it in rings. An explanation of the spectrum of hydrogen has been given on this view by Bohr; in connection with this theory Bohr uses the quantum which has already been referred to on p. 33, and at present his views are very popular. But perhaps the most interesting view is that put forward by Langmuir according to which the electrons are arranged round the nucleus in shells, each electron being in a fixed position. The first shell may have two electrons, the first layer of the second shell eight, the second layer of the second shell eight, the first layer of the third shell eighteen electrons, the second layer of the third shell eighteen, and the first layer of the fourth shell thirty-two. If a layer has its full complement of electrons, the atom is inert. It neither gains nor loses an electron easily. Thus we have helium with the atomic number 2, neon with the atomic number $2 + 8 = 10$, argon with the atomic number $2 + 8 + 8 = 18$, krypton with the number $2 + 8 + 8 + 18 = 36$, xenon with the number $2 + 8 + 8 + 18 + 18 = 54$, and niton with the number $2 + 8 + 8 + 18 + 18 + 32 = 86$.

Structure of Sodium Fluoride.—It is perhaps going into too much detail, but the explanation of chemical combination is so interesting on Langmuir's view, that one illustration, the formation of sodium fluoride, will be given. Fluorine has a shell and a layer less one electron, *i.e.*, the atomic number nine, and sodium a shell and a layer plus one electron, *i.e.*, the atomic number eleven. In Langmuir's words "The sodium has one more electron than is necessary to give a stable structure while the fluorine has an electron too few. The extra electron of the sodium atom passes over completely to the fluorine atom. This leaves the sodium atom with a positive charge and the fluorine atom with a negative charge. If the two charged atoms were alone in space they would be drawn together by the electrostatic force, and would move as a unit and constitute a molecule. However, if other sodium and fluorine atoms are brought into contact with the "molecule," they will be attracted as well as the first one was.

There will result (at not too high a temperature) a space lattice consisting of alternate positive and negative charged atoms, and the "molecule" of sodium fluoride will have disappeared. Now this is just the structure which we find experimentally for sodium fluoride by Bragg's method of X-ray crystal analysis. There are no bonds linking pairs of atoms together. The salt is an electrolytic conductor only

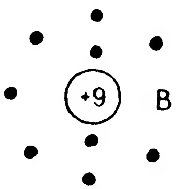


Fig. 34. FLUORINE ATOM.

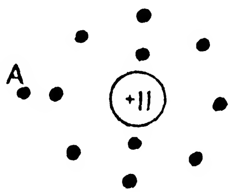


Fig. 35. SODIUM ATOM.

in so far as its ions are free to move. In the molten condition or when dissolved in water, therefore, it becomes a good conductor."

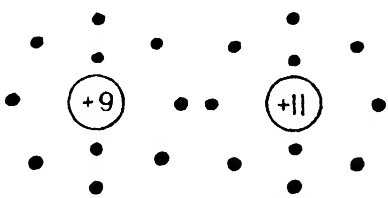


Fig. 36. SODIUM FLUORIDE.

The formation of sodium fluoride according to the above theory can be illustrated very neatly by diagrams. Figs. 34 and 35 represent the fluorine and sodium atoms. The electrons are represented by black spots. The diagrams ought to be three-dimensional, the electrons ought to form a shell, not a ring, but in the case under consideration it is simpler to present them as a ring and the principle of the arrangement is not altered thereby. In the case of fluorine the nine electrons are just neutralised by a positive charge of nine units on the nucleus, and in the case of sodium the eleven electrons are just neutralised by a charge of eleven units on the nucleus. The electrons are most stable when the rings are

complete ; hence, if we bring the two atoms together, the odd electron A goes into the empty place B, as shown in Fig. 36. The atoms are now no longer neutral. The fluorine atom on the left has 10 electrons and its nucleus only a charge of 9 units, hence as a whole it has one negative charge. Similarly the sodium atom has 10 electrons, but its nucleus has a charge of 11 units. Hence as a whole it has one positive charge. The two atoms are thus bound together by electrostatic attraction.

The Mass Spectrograph.—It has been mentioned that the atomic number of an element is now regarded as a more important characteristic than its atomic weight. The atomic weights as determined by the methods described in the text-books on chemistry are averages. The atomic weight of chlorine, for example, is 35·46 ; chlorine is apparently a mixture of two gases of atomic weights 35 and 37 which have both the same atomic number 17, and which have identical chemical properties ; they are therefore inseparable by chemical methods. Such substances which have different atomic weights, but the same atomic number and the same chemical properties, are termed isotopes. Since in the case of chlorine the atomic weight of the mixture, 35·46, is much nearer 35 than 37, it is clear that the lighter isotope must be present to a greater extent than the heavy one.

Our knowledge of the isotopes of the non-radioactive elements is derived chiefly from the method of positive ray analysis first introduced by J. J. Thomson and afterwards developed by Aston. This method makes use of a piece of apparatus known as the mass spectrograph. When electricity is conducted through a gas at a low pressure the atoms are ionised, *i.e.*, each neutral atom loses an electron. The electron rapidly acquires a high velocity in the one direction and becomes a kathode ray. The atom after the loss of the electron has a positive charge, acquires a velocity in the other direction, and becomes a positive ray. Owing to the much greater mass of the atoms the velocity of the positive ray is much less than that of the kathode ray.

In positive ray analysis a stream of positive rays, *i.e.*, of

atoms with positive charges, is allowed to pass from the vessel in which the electrical discharge is taking place through a fine tube. Issuing from this tube we have consequently a stream of atoms of different weights and moving with different velocities. This stream is subjected to an electric and a magnetic field, and the atoms are deflected from their rectilinear paths by the electric and magnetic forces acting on them. The deflection depends on the weight and velocity of the atom; consequently if there is more than one kind of atom in the stream, the latter is resolved by the electric and magnetic fields into constituent streams. Positive rays act upon a photographic plate, so the deflection of these streams is measured by allowing them to fall upon a photographic plate; then it is merely a matter of mathematics to calculate the weight of the atoms in each case. The apparatus sorts out the different kinds of atoms by a series of impressions on a photographic plate, just as a spectrograph, the instrument used for photographing spectra, sorts out different wavelengths; hence the designation mass spectrograph.

Resolving Power of Telescopes.—So far we have given a brief account of the great advance that has been made in our knowledge of the structure of the atom in the last ten years. The advance in our knowledge of the stars that has taken place in the same period is equally striking; indeed the student who now goes back to the subject after being away from it for that time, finds himself quite lost in admiration at the triumphs of observation and reasoning achieved and at the vistas which open out before the imagination. The new work has not yet got into the books on popular astronomy[1], though it is suitable for treatment in such books, and it exists in addition to, and quite independent of, such ideas of the relativists as that space itself is limited, and that some of the distant star clusters may be reflections of our own stellar system, owing to space going back on itself.

To the observer who has only his eyes to aid him the stars and planets are merely bright points. If, however, a telescope is used to magnify them, the planets show the characteristic

[1] With the exception of Hale's *The New Heavens*.

forms described in the books on popular astronomy ; they are comparatively near us and belong to our own solar system. But the stars still remain points. The planets execute wide movements across the whole heavens, and since there is much to measure, it has been possible to work out the structure of the solar system. But any characteristic motion which the stars possess is extremely small owing to their immensely greater distances. Hence it seemed improbable that we should ever know much about them.

The human eye can see two dots separate, when they subtend an angle of one or two minutes. This angle is said to be its resolving power. If they are nearer than this, the eye sees them as one dot. The reader may test this by propping the book against the wall and looking at Fig. 37 from a distance of 7 feet, when the two dots should be about $1\frac{1}{2}$ minutes apart. If his acuity of vision is normal, he should see them separate at smaller distances than this and should see them as one at greater distances than this. Individuals vary, however, considerably as regards their acuity of vision. The use of a telescope increases the resolving power ; the resolving power obtained by a telescope is calculated by dividing the diameter of its object glass measured in inches into 5, when the quotient gives the result in seconds of angle. For example, the Mark IV signalling telescope so widely used in the British army has an object glass with a diameter of two inches ; its resolving power is consequently $\frac{5}{2}''$ or $2\frac{1}{2}''$. By its means we can separate two objects which are only $2\frac{1}{2}''$ apart. The object glass of the great Yerkes telescope, the most powerful refracting telescope hitherto employed for astronomical observation, has a diameter of 40 inches, so it resolves two objects that are $\frac{1}{8}''$ apart. The apparent angular diameters of Venus, Jupiter, and Saturn vary respectively

Fig. 37.

from 11 to 67 seconds, 32 to 50 seconds, and 14 to 20 seconds, so they come well within the range of a Mark IV telescope.

The star nearest to us, α Centauri, is at a distance of 4·3 light years, *i.e.*, the light takes 4·3 years to come from it, and the diameter of the sun is 866,500 miles. A simple calculation shows therefore, that the sun subtends an angle of ·0070 seconds at the nearest fixed star, and if the nearest fixed star were the same size as the sun, it should subtend the same angle at the earth. This is so far below the resolving power of the most powerful telescopes, that it seemed hopeless to think we should ever be able to measure the angular diameter of any of the stars. It consequently came as a great surprise to those not intimately in touch with the subject, when it was intimated in 1920 that the angular diameter of one star, Betelgeuse, had been successfully measured at Mount Wilson in America, and that it had the value of ·046″. It came also as additional surprise to learn that the result had been predicted before the actual measurement was made.

Giant and Dwarf Stars.—If we heat a poker in the fire, it glows first with a dull red heat, and the colour becomes whiter as the temperature rises. This is a general property of all solid bodies and of gaseous bodies which are so large as to be opaque, and from the colour it is possible to make a determination of the temperature. If the body were of such a nature that its surface did not reflect light at all, the determination could be made with absolute accuracy; in other cases it is possible to make it with fair accuracy. Thus the temperature of the stars has been determined from their colour, and the results vary from 2000° K* in the case of the red stars to 20,000° K in the case of the blue stars. The spectra of the stars have been studied; they bear out the conclusions established about the temperatures, and at the same time show that there is little difference in the chemical constitution of the stars.

No information can be obtained about the mass or density of an isolated star, but when two stars revolve round each

* Degrees Kelvin i,.e. degrees centigrade reckoned from the absolute zero.

other, it is possible by elementary mathematics to calculate the masses, and when one passes in front of the other and eclipses it, to calculate the density. Thus the masses and densities of a number of stars have been determined, and it has been found in these cases that stars with the same temperature always fall into two classes, a class of large stars with a high luminosity and a low density and a class of dense stars with a low luminosity. Also the weights of the stars are remarkably similar, varying only about fiftyfold, whereas their luminosities and densities vary one-millionfold.

These facts caused Prof. H. N. Russell to put forward the hypothesis in 1913, that each star in its life passes through two stages, the giant stage and the dwarf stage. Each star starts as a giant with an extremely low density and a comparatively low temperature. It has then a red colour and behaves as a perfect gas. Under the influence of gravitational attraction it contracts. This causes its temperature to rise. Finally it can contract no more, the temperature becomes a maximum, and the star, which has become a dwarf, commences to cool. Thus each temperature is passed through twice, once on the upward journey and once on the downward journey. The giant stage of the star's life is passed through more rapidly than the dwarf stage. It is even thought that in the spiral nebulae we can see giant stars in the process of birth; these nebulae are whirling masses of gas which owing to their rapidity of motion throw off gaseous stars as a Catherine wheel throws off sparks, or as the planets themselves were thrown off in Laplace's nebular hypothesis.

It is tempting to speculate on the constitution of the giant stars, masses as great as our own sun, but dimensions very much greater, densities less than the density of our own atmosphere, temperatures much higher than we can ever attain in the laboratory, and radiations intermediate between the ultra-violet and soft X-rays produced in great quantities and playing a large rôle in the star's economy. These and other ideas are dwelt on at length in Prof. Eddington's address to Section A of the British Association in 1920.

Measurement of Angular Diameter of Betelgeuse.—It followed

as a consequence of the giant and dwarf hypothesis, that the star Betelgeuse should have the greatest angular diameter of all stars, namely about ·051.″ This quantity is beyond the power of even the largest telescope, but Michelson suggested that it might be measured by an interference method.

Young's experiment on the interference of light has already been described on p. 24. Light from a slit S (Fig. 18) falls on two parallel slits A and B. The two streams of light emerging on the other side fall on a screen CF, overlapping on the central portion ED and forming a series of light and dark bands there. For the bands to be sharp for a given breadth of slit S, it is necessary for the two slits A and B to be extremely close together. If they are further apart, the bands are blurred; if they are further apart still, the bands disappear altogether. It can be shown by elementary mathematics, that the bands disappear when l, the distance apart of the slits A and B, satisfies the relation $\alpha = \lambda/l$; λ is the mean wave-length of the light, and α is the angle subtended by the breadth of the slit S at the screen AB. Suppose now that the slit S is at a great distance, and that we have some means of moving the two slits A and B apart, *i.e.*, of increasing the value of l. If l originally is very small, the bands will be sharp: then in the inequality $\alpha = \lambda/l$, the right hand is much larger than the left. If however l is increased, the bands become fainter, and finally, when the two sides are equal, they disappear altogether. Thus by determining the value of l for which the bands disappear and from a knowledge of λ, α can be calculated.

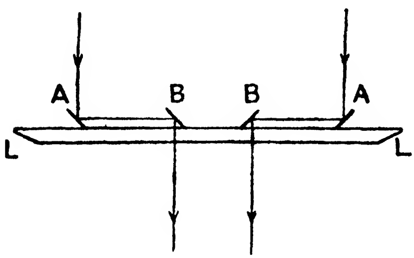
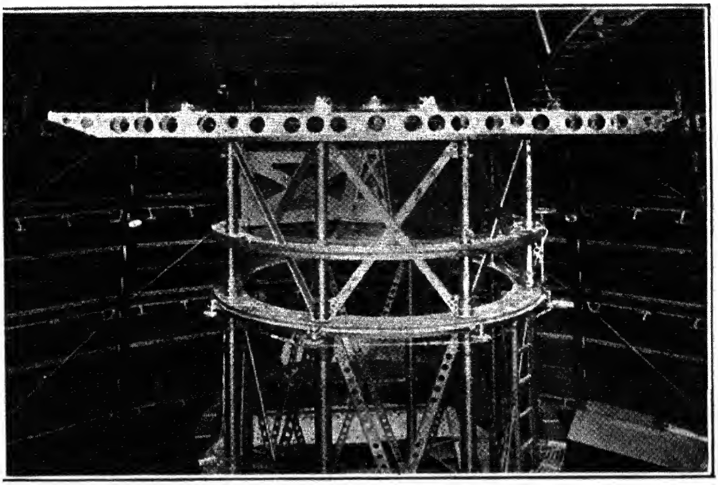
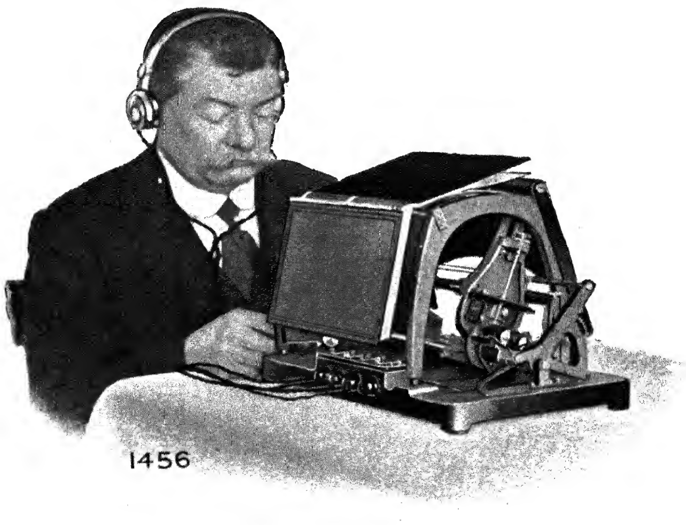


Fig. 38.

At Mount Wilson the star Betelgeuse took the place of the slit S. Owing to the substitution of a circular disc of uniform brightness for the slit, the formula alters somewhat and becomes $\alpha = 1.22\lambda/l$. The inter-



Twenty-foot Michelson Interferometer for measuring star diameters, attached to skeleton tube of 100-inch Hooker Telescope in the Mount Wilson Observatory.



THE OPTOPHONE

(Barr & Stroud, Limited)

The Instrument which enables the blind to hear ordinary printed matter instead of reading it.

PLATE IV.

ference bands were formed in the focal plane of the 100 inch Hooker telescope. Two adjustable plane mirrors A and A (Fig. 38 and Plate IV.) took the place of the slits A and B in Fig. 18. These mirrors moved along a steel girder LL, 20 ft. in length, which was fixed across the upper end of the tube of the telescope. The photograph shows the girder in position. The mirrors A A reflected the light from the star along the girder to two other mirrors B B, 4 ft. apart, which in turn reflected it down the tube of the telescope.

It was found that the bands disappeared, when the mirrors A A were 10 ft. apart. Assuming as the mean value of λ 5500 A.U. α works out as ·046″. If, however, we assume that the star is not a uniform disc, but that its brightness falls off towards the edge according to the same law as for the sun, α works out at ·049″ in close agreement with the theoretical prediction. Similarly the angular diameter of Arcturus has been found to be ·024″ as against a predicted value of ·020″.

CHAPTER V

THE PRIMARY COLOURS

THE properties of the primary colours and their mixtures form one of the most fascinating studies imaginable, equally interesting to photographers, artists, physicists, and the lay public. At the outset we must emphasise the fact, that mixing or adding together two coloured lights does not produce the same result as mixing or adding together two pigments, of the same colours as the lights.

Adding Coloured Lights.—Let us suppose we have a white screen in a darkened room, and that by means of three lanterns we are able to throw three discs of light upon this screen. We can, for example, imagine we are in a theatre or music hall, and that the three lanterns are situated in the front of the dress circle, each provided with its own operator, that the screen is on the stage, and that all lights are extinguished so that the theatre is perfectly dark. It is, of course, not necessary for the success of the experiment that it should be performed on this ambitious scale, but the description is probably easier to understand when the experiment is performed in this way, instead of by one of the methods used in the laboratory. We shall suppose that one of the spots or discs of light on the otherwise dark screen is coloured red, another green, and the third blue. Then by tilting their lanterns the operators can make these discs move across the screen, and superimpose on one another. Usually the coloured light in theatres is produced by holding a sheet of coloured gelatine in front of the lantern, but the coloured gelatine employed in theatres is unsuitable for our experiment. The colours are not nearly saturated enough, *i.e.*, not intense nor pure enough. Even the best green that the operator

throws upon the villain contains a good deal of white in it. The red required for our experiment must be a pure red without any tint of orange, somewhat similar to the red of the railway signal lamps ; the green must contain neither yellow nor blue, and must be purer than the green of the signal lamps ; the blue must be an ultramarine with a good deal of violet in it.

Under these circumstances, if the red is superimposed on the green we obtain yellow. Strong red imposed on weak green gives orange, weak red on strong green yellowish green. Green superimposed on blue gives peacock blue. Red superimposed on blue gives magenta, and red on a stronger blue gives purple. Red, green, and blue superimposed on one another make white. If white is dimmed, we get gray ; if orange is dimmed we get brown. Superimposing white on any colour makes it paler. Thus by means of the three colours, red, green, and blue, we obtain nearly all the colours that occur in nature. They do not give us violet, but pure violet does not occur frequently in nature. So red, green, and blue are termed the primary colours. Putting our results in the form of a table we obtain :

Red + Green + Blue = White
Red + Green = Yellow
Green + Blue = Peacock Blue
Blue + Red = Magenta
Red + Peacock Blue = White
Green + Magenta = White
Blue + Yellow = White

Peacock blue, magenta, and yellow are termed the three complementaries, since each of them combined with one of the primaries gives white. Peacock blue is sometimes referred to as minus-red, since it is the colour obtained by subtracting red from white, and in the same way magenta and yellow are referred to as minus-green and minus-blue.

The Colour Triangle.—The colour triangle, which is represented in Fig. 39, is a very useful method of exhibiting the relations of the primary colours. The first attempt at a diagram of this nature is given in Newton's *Opticks*, but the method was not developed fully until it was taken up by

Helmholtz and Maxwell two centuries later. In the triangle, which is an equilateral one, colours are represented by points. The primary colours are at the corners. The colour formed by mixing any two coloured lights in equal proportions is represented by a point equidistant from them; thus the complementaries, peacock blue, magenta, yellow, are at the midpoints of the sides. White, which is formed by adding red, green, and blue in equal proportions, is represented by a point at the centre of the triangle equidistant from the corners. If any two colours are mixed in unequal quantities, if, for example, *a* units of the one are added to *b* units of the other, the mixture is represented by a point on the line joining them, which divides this line in the ratio *a* to *b*, and is nearer the colour of which most was taken. Thus, since peacock blue and red added together in the proportion of two of the former to one of the latter make white, white is represented by the point on the median twice as far from red as from peacock blue. This is sometimes expressed by saying that a red is twice as strong as a peacock blue of the same intensity. In the same way green is twice as strong as magenta, and blue twice as strong as yellow. The spectrum colours, red, orange, yellow, yellowish-green, green, peacock blue, lie along the first and then somewhat outside the second upper side of the triangle. The violet end of the spectrum is below blue outside the triangle. The colours along the base are, in order, red, rose-pink, magenta, purple, blue. The saturated colours lie along the sides of the triangle; the paler colours inside round about white. For example, if we travel along the median from the red corner, the red gets paler and paler until it merges into white; the white then takes on a faint peacock-blue tinge which increases in saturation until the side of the triangle is reached.

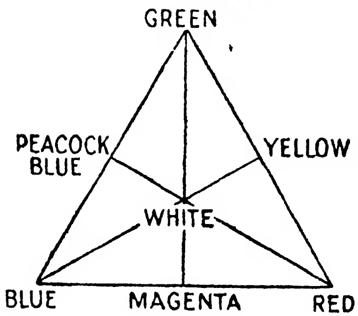


Fig. 39.

One advantage of the colour triangle is that it enables us to describe a colour by specifying the point which represents it. This is much more accurate than using words, because most people are not educated in the expressions for the finer shades. It enables us to see at a glance the effect of mixing any two coloured lights in any proportions, and it is useful in connection with simultaneous and successive contrast. We shall deal with this point later.

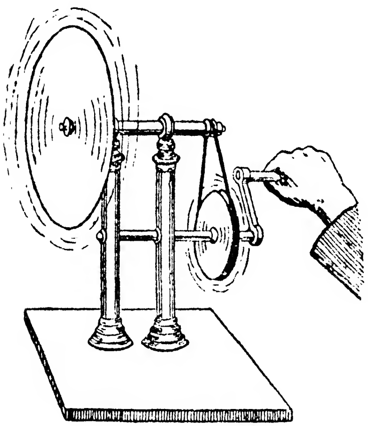


Fig. 40.

Maxwell's Colour Disc.—Fig. 40 represents an arrangement for mixing colours, known as Newton's or Maxwell's disc, though a special form of it was mentioned in the second century of our era in the *Optics* of Ptolemy. The different sectors of the disc are painted different colours; when the disc is spun round, owing to the rapid motion the colours blur, and the whole surface appears one uniform hue. The results obtained in this way agree with those given by the arrangement of three lanterns described earlier in the chapter.

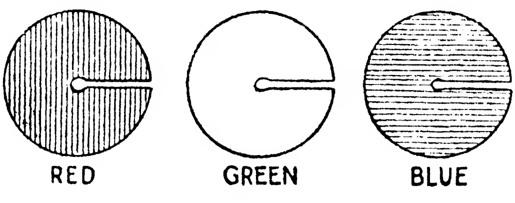


Fig. 41.

Suppose, for example, it is desired to mix red, green, and blue in given proportions, red, green, and blue discs are taken, and slits cut in each as illustrated in Fig. 41. Two discs are then slipped into the slit of the other—cut out three

models with a pair of scissors, and you will see what is meant—and the three combined into a single disc as in Fig. 42. This single disc has three sectors, a red, a green, and a blue, all of variable angle, for the angles can be altered by slipping the discs round. When it is fixed on the apparatus shown in Fig. 40 and rotated, the colours mix in the proportions given by these angles. It is found that when the angles are each 120°, and the disc is strongly illuminated, it appears white.

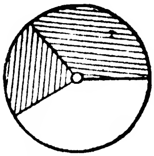


Fig. 42.

Other Methods of Mixing Coloured Lights.—Fig. 43 represents another method of mixing colours, Lambert's method. P is a glass plate, a stripped photographic plate, for example. A and B are pieces of red and blue coloured paper laid out on a piece of black velvet cloth. The eye can see A through the glass, and B by reflection from the surfaces of the glass; they consequently appear superimposed and the colours mix. With the arrangement shown in the diagram the red would appear much brighter than the blue. By holding the glass plate so that the reflection takes place at grazing incidence, the blue can be made brighter. This might also be done by illuminating it with a lamp.

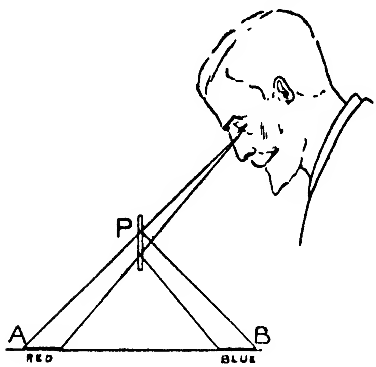


Fig. 43.

The spectrum colours themselves can be mixed by the arrangement shown in Fig. 4 (page 3). RV is a spectrum formed by a glass prism. It is received by a lens which focusses it on a screen W, where an image of the prism is formed. If all the colours of the spectrum are received by the lens, this image is white. But if a sheet of cardboard is placed at VR with two slits in it, one to let through the red and the other to let through the green, then at W we shall have a red and a green

image of the prism superimposed, and the result will be yellow. In the same way by having the slits at other points in the spectrum, the effect of mixing other colours can be tried. This is the manner in which Newton first studied the subject and laid down its principles two and a half centuries ago.

The disadvantage of methods such as those represented in Figs. 40 and 43 is that coloured papers never give very intense or pure colours. Coloured glass or coloured gelatine as used in the first method described is better in this respect, and spectrum colours are best of all.

Coloured Pigments.—So far we have dealt with adding or mixing coloured lights. We have now to consider the mixture of coloured pigments. This is a subject with which to a certain extent we are all familiar, owing to our experience with water colour paint-boxes when children. We then learned that approximate representations of all colours could be produced by mixing red, yellow, and blue, or more accurately, crimson, yellow, and peacock blue, *i.e.*, the three complementaries on the colour diagram. For crimson and yellow mixed in varying proportions gave red and orange, yellow and blue gave green, and blue and crimson mixed in varying proportions ultramarine-blue and the purples. Hence these colours have been termed by the artists the primary or elementary colours, for human nature has had a natural tendency to think in terms of elements, especially in medieval times; some painters have restricted themselves to the use of these three colours, adding black for the purpose of darkening them and obtaining the browns and greys, although they would undoubtedly have obtained a better representation of the hues of nature, if they had used other colours as well.

If we desire to renew our studies in mixing coloured pigments, then we can go back to the crimson lake, gamboge, and Prussian blue of the water colour paint-boxes. Or we may use instead Arnold's waterproof inks, carmine, yellow, and Prussian blue, which give more intense colours. If we wish to exhibit the mixing of pigments to a large audience, the best method is to get six glass cylinders, fill the first with a crimson

liquid, the second with a yellow liquid, and the third with a blue liquid, and then pour the liquids together into the fourth, fifth, and sixth to make orange, green, and purple. The glasses should be held before a well-lighted white background. Fuchsin, naphthol yellow, and copper sulphate are suitable colours to use.

If we add yellow and blue pigments we get green. If we add yellow and blue lights we get white. Whence comes the contradiction ?

A yellow pigment appears yellow because, when the constituents of white light fall upon it, the blue and violet are absorbed, and red, yellow, and green reflected. Most yellows occurring in nature are not very pure, and reflect red and green as well as yellow. A blue pigment appears blue because it absorbs red and yellow ; most blues occurring in nature are not very pure, and reflect green as well as blue. When the yellow and blue pigments are mixed, the mixture absorbs all the colours absorbed by its components singly, *i.e.*, blue, violet, red, and yellow. Green is the only colour left. It alone is reflected and the mixture appears green. A mixture of pigments gives only the colour which neither absorbs, not the sum of the two colours, as we obtain when adding lights.

Three Colour Printing.—It is difficult to say offhand what the result of mixing any two pigments will be, because pigments which appear approximately the same in colour often show wide differences when examined spectroscopically. For example, we may have a yellow, as above, which reflects red, yellow, and green, or we may have a yellow which is quite pure, and reflects only a narrow yellow strip in the spectrum. If we mix a very pure blue and a very pure yellow, the result is black, for the mixture absorbs all the colours of the spectrum. Theoretically the best three colours to use in three-colour printing are the three complementaries of the colour triangle. Suppose we divide the spectrum into three parts, red end to middle of yellow, middle of yellow to middle of peacock blue, middle of peacock blue to violet end. Then the yellow used in three-colour printing should reflect the first two-thirds of the spectrum, the peacock

blue the last two-thirds and the magenta the two end thirds. The yellow impression is made first, then the magenta or carmine, and finally the blue. The last diagram on the plate facing p. 6 is an example of three-colour printing. The other diagrams of this plate required four colours to get the tints right, the additional impression being in green. The number of impressions employed in producing a colour print can usually be made out by examining it with a lens. It is impossible, of course, for the three-colour printer to get inks which exactly meet his theoretical requirements, and the result obtained is generally a compromise. Sometimes also the inks are deliberately changed; the three complementaries while most suitable for general purposes may not be the best colours for some particular purpose. If the three complementaries each reflect their proper two-thirds of the spectrum, when printed on the top of one another they should give black.

Suppose we print two of the complementaries on one another in varying strengths on a white background, then the resultant colour lies on the colour triangle in the quadrilateral bounded by the sides and medians through these complementaries. The heavier the impression, the nearer the colour is to the side through the colour of the impression. Thus, if the impressions are yellow and magenta, we can get any colour in the area between white, yellow, red and magenta, because printing magenta means taking green away and printing yellow means taking blue away from white. Thus the point representing the colour starts at white, and moves away from green and blue in proportion to the strengths of the magenta and yellow impressions.

The Wratten Filters.—Kodak Ltd. sell two sets of coloured gelatine filters which illustrate the properties of the colour triangle excellently. The first set, the standard tricolours, let through each one-third of the spectrum and give red, blue, and green. The second set, the complementaries, let through each a different two-thirds and give peacock blue, yellow, and magenta. When the complementaries are combined two and two together, they give the primaries, a perfect match being

obtained in each case, and when all three complementaries are combined they give black.

Complementary Colours.—So far we have referred to the three colours at the corners of the triangle as primaries and the colours opposite to them as complementaries. But the triangle shows that there are other pairs of complementaries as well. Suppose we draw any line PQ through white to meet the sides at P and Q. Then obviously the colours represented by P and Q must combine together to give white, and are therefore true complementaries. The point P in Fig. 44 gives an orange yellow, and the point Q a blue intermediate in colour between peacock blue and ultramarine.

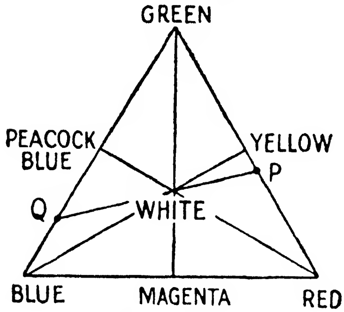


Fig. 44.

Hitherto we have thought of the red, blue, and green at the corners of the triangle as being the colours transmitted by good filters, *i.e.*, not spectrally pure but each containing a range of wave-lengths. Suppose that they each consist of a single wave-length, then it is found that there are other wave-lengths to which they are complementary. Or, in other words, it is found that there are pairs of wave-lengths in the spectrum, light of which when combined together in suitable proportions makes white. The most complete table of such pairs of wave-lengths has been drawn up by Helmholtz and is given below:

	Wave-length.		*Wave length.*
Red	6562 A.U.	Greenish-blue	4921 A.U.
Orange	6072 ,,	Blue	4897 ,,
Yellow	5853 ,,	Blue	4854 ,,
Yellow	5739 ,,	Blue	4821 ,,
Yellow	5671 ,,	Dark Blue ...	4645 ,,
Yellow	5644 ,,	Dark Blue ...	4618 ,,
Greenish-yellow	5636 ,,	Violet ...	4330 ,,

But Helmholtz is not quite so definite on the subject as is generally supposed. After describing the arrangement employed for determining the complementary colours—a refinement of that described at the foot of p. 74—and mentioning all the precautions necessary, he states that it is difficult to obtain results. The two complementary colours are scattered unequally by the screen, after-images exercise a disturbing effect, and the middle and outlying parts of the retina give different results. The white is obtained most easily with yellow and dark blue, not so easily with greenish-yellow and violet, or yellow and blue, and less easily still with red and greenish blue.

Newton who worked with a much rougher experimental arrangement than Helmholtz, states, *Opticks*, Bk. I, p. 116, that never by mixing only two spectral colours could he produce a perfect white, but only "some faint anonymous colour." This was probably due to the rough nature of his apparatus, or possibly he had a very high standard of what a perfect white ought to be.

Mistakes in Judging Colour.—The colours of bodies depend not only on themselves but to a certain extent on the nature of the light falling on them. Thus everything acquires a golden tint in bright sunshine. If we exclude sources of light such as lamps and flames, all bodies are visible by borrowed light. In a room illuminated by a candle, rays of light from the candle fall on all objects in the room ; some of them are absorbed, but others are reflected, and diverge out from these objects as if they were independent sources. The room is filled with rays, criss-crossing in all directions ; some of them enter the eye, and as a result the objects in the room are visible.

If the room is illuminated by candles, which are relatively rich in red rays but deficient in blue, red objects appear bright but blue objects appear dark. This is only natural, because the blue object cannot reflect blue rays if the blue rays are not there to reflect. The fact that the colours of objects depend on the rays with which they are illuminated, can be shown in an extreme case by passing skeins of coloured wool along a spectrum. If the colours of the wool are pure, each skein

appears bright only when illuminated by light of its own colour ; otherwise it is dark.

All the artificial lights in common use are redder than daylight. Consequently they make blues darker than they should be, and colours matched by artificial light may not appear the same by daylight. To obviate this difficulty various "daylight lamps" have been introduced, in which the colour is modified by screens or reflectors to give the actual tint of daylight. These lamps are in use in some warehouses. There is no difficulty in making them ; it is quite an easy matter removing some of the excessive red rays, but of course this diminishes the illuminating power of the lamp, and less light is obtained for the same electrical energy.

But the eye is liable to mistakes in judging colour quite apart from the effect of the illuminant. I cannot illustrate this better than by describing an experience of my own. I was paying an account two days after the stamp for affixing to receipts was changed from the red penny to the orange twopenny. When I received the receipt, which was on lemon-coloured paper, the stamp appeared red, and I started to speak to the clerk about putting on the wrong stamp, when it suddenly occurred to me that the colour was an illusion ; I consequently examined the stamp and found it was a twopenny one after all. The lemon-coloured background made the orange stamp appear red. The yellow background drove, so to speak, the yellow out of the orange. But I find it necessary to be off my guard to be deceived by an illusion of this kind. I have always seen the stamp on this particular receipt as orange since.

The phenomenon, an instance of which has just been described, is known as simultaneous contrast. It makes a small white object on a coloured ground appear to have the colour complementary to the ground. Thus white on a blue ground appears pink. The effect is heightened by putting a thin sheet of tissue paper over the object, but disappears if the object is surrounded by a black border. Also two complementary colours placed side by side appear heightened in

intensity. There is a case on record in which simultaneous contrast almost led to a lawsuit. A cloth, woven of materials supplied to the manufacturer by the person who required the cloth, showed pinks which were the result of illusion, the material being actually grey.

Closely allied to simultaneous contrast is successive contrast. If we look at a bright red light for some time, until the eye becomes fatigued with red, and then look at a white surface, the latter appears peacock blue. White appears peacock blue after red, and red after peacock blue, just as lukewarm water feels hot if the fingers have first been dipped in cold water, and cold if the fingers have first been dipped in hot water. It is the same with other colours ; if the eye is fatigued with any colour, the white surface appears of the complementary colour.

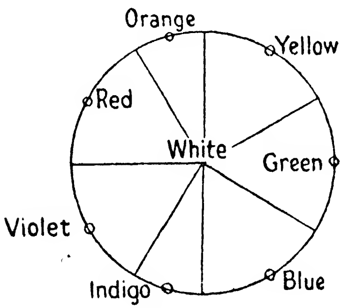


Fig. 45.

Colour Circles.—It was mentioned that the first attempt at a colour diagram was made by Newton in the *Opticks*. Fig. 45 represents his diagram. The seven colours of the spectrum are arranged round the circumference of a circle with white at the centre ; the sectors in which orange and indigo are situated are only half as broad as the others, being, of course, analogous to semitones, whereas the others correspond to tones. Newton used this diagram for predicting the result of mixing coloured lights, just as we have used the triangle.

Goethe in his *Farbenlehre* or *Doctrine of Colours* also has a circle of colours, designed not for numerical work, but for exhibiting the aesthetic relations of colour. The *Farbenlehre*, which appeared in 1810, more than a century after the *Opticks*, was written from the old Aristotelian standpoint, a sample of which has already been given in the views of Dr. Barrow on p. 5. The colours according to Goethe are acts of light, its active and passive modifications, and he never

gets any nearer the matter than this. He also states that red partly *actu*, partly *potentiâ*, includes all other colours. But his preface is marked by a great contempt for Newton's work on the spectrum and a still greater ignorance of it; apparently he never saw the fundamental experiment with the prism. Writing under the impression that he has demolished the Newtonian theory, he states:

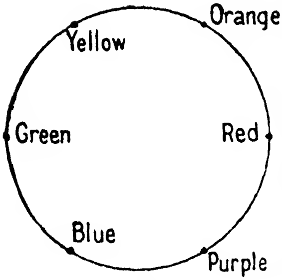


Fig. 46.
(*Goethe's Circle of Colours.*)

"It was impossible to write or even prepare the way for a history of the theory of colours while the Newtonian theory existed; for no aristocratic presumption has ever looked down on those who were not of its order with such intolerable arrogance as that betrayed by the Newtonian school in deciding on all that had been done in earlier times and all that was done around it. With disgust and indignation we find Priestley, in his *History of Optics*, like many before and after him, dating the success of all researches into the world of colours from the epoch of a decomposed ray, or what pretended to be so; looking down with a supercilious air on the ancient and less modern inquirers, who after all had progressed quietly in the right road, and who had transmitted to us observations and thoughts in detail which we can neither arrange better nor conceive more justly."

M. E. Chevreul has a beautiful reproduction in colours of a circle of colours or "chromatic circle of hues," as he calls it in his book *The Principles of Harmony and Contrast of Colours*, published in 1835. This circle has altogether 72 different hues, 6 red, 6 orange-red, 6 orange, 6 orange-yellow, 6 yellow, 6 yellow-green, 6 green, 6 green-blue, 6 blue, 6 blue-violet, 6 violet, and 6 violet-red.

Ruskin has a circle of colours in *The Laws of Fesole* and Munsell has one in *A Grammar of Colour*. The circle, however, as a means of representing the relations of colour, is much inferior to the triangle. Munsell, whose scheme is very

carefully thought out, finds it necessary to put red at the end of a spoke projecting out from the circle, so as to get it twice as far from the centre as blue-green, because, in his phraseology, "red is twice as strong as blue-green." Figs 47 & 48 give Munsell's and Ruskin's circles respectively.

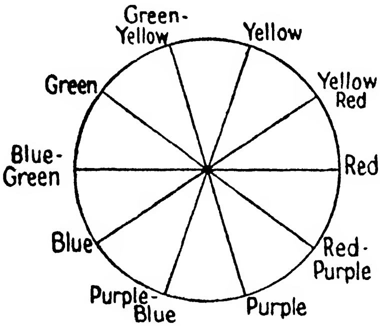


Fig. 47.

Ruskin refers to his circle as the "twelve zodiacal colours." The chapter from which it is taken deals with painting in water colours. The different tints are to be made with gamboge, emerald green, cobalt, carmine, and vermillion by mixing them in the proportions specified. Ruskin states that he had vainly endeavoured to persuade Messrs. Winsor and Newton to prepare these colours in the form of powders, so

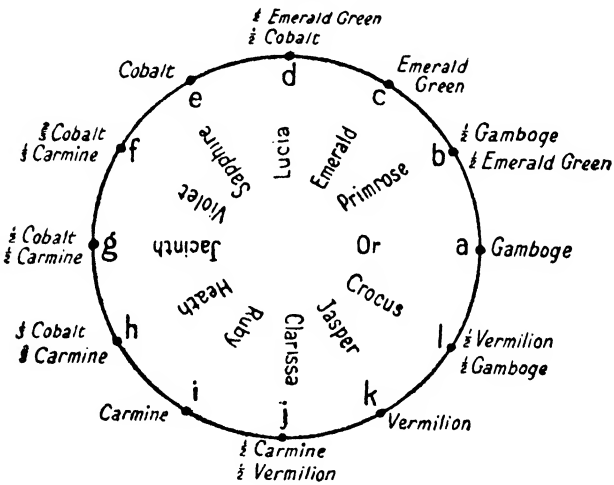


Fig. 48.

that students could mix them in the required proportions. The words inside the circle, "Sapphire," "Lucia," etc., are his names for the colours.

The principal use of the zodiacal arrangement, he states, is that each colour is placed over against its proper opponent, Jacinth being the hue which most perfectly relieves Or, and primrose the most lovely opponent to Heath. The best rubrics of ecclesiastical literature are founded on the opposition of Jasper to Sapphire.

We have already quoted from Goethe ; we shall now give a characteristic extract from Ruskin on colour. It may interest those readers who have hitherto found the treatment prosaic, and at the same time give the others something to puzzle over. It will be noted that for Ruskin the primary colours are red, yellow, and blue.

"These things, then, above named, without any debate, are to be received by you as *standards* of colour : by admiration of which you may irrefragably test the rightness of your sense, and by imitation of which you can form and order all the principles of your practice. The morning sky, primarily, I repeat ; and then from the dawn onwards. There are no greys or violets which can come near the perfectness of a pure dawn ; no gradations of other shade can be compared with the tenderness of its transitions. Dawn, with the waning moon (it is always best so, because the keen gleam of the thin crescent shows the full depth of the relative grey), determines for you all that is lovely in subdued hue and subdued light. Then the passages into sunrise determine for you all that is best in the utmost glory of colour. Next to these, having constant office in the pleasures of the day, come the colours of the earth, and her fruits and flowers ; the iron ochres being the standards of homely and comfortable red, always ruling the pictures of the greatest masters at Venice, as opposed to the vulgar vermilion of the Dutch ; hence they have taken the general name of *Venetian* red : then, gold itself for standard of lustrous yellow, tempered so wisely with grey in the shades ; silver, of lustrous white, tempered in like manner ; marble and snow, of white pure, glowing into various amber and rose under sunlight ; then the useful blossoms and fruits ;—peach and almond blossom, with the wild rose, of the paler reds ; the clarissas, of full reds, etc. ; and the fruits,

of such hues modified by texture or bloom. Once learn to paint a peach, an apricot, and a greengage, and you have nothing more to know in the modes of colour enhanced by texture. Corn is the standard of brown—moss of green; and in general, whatever is good for human life is also made beautiful to human sight, not by 'association of ideas,' but by appointment of God that in the bread we rightly break for our lips, we shall best see the power and grace of the light He gave for our eyes.

"The perfect order of the colours in this gentle glory is, of course, normal in the rainbow—namely, counting from outside to inside, red, yellow, and blue, with their combinations—namely, scarlet, formed by yellow with red; green, formed by blue with yellow; and purple, formed by red with blue."

Priestley's *History and Present State of Discoveries relating to Vision, Light and Colour*, to which Goethe so indignantly refers, was a large two volume book, published by subscription in 1772, which is still of great value. It has an interesting dedication in the eighteenth century manner to the Duke of Northumberland, commencing as follows:

> "My Lord,
>
> "It is with peculiar satisfaction that I dedicate the first volume of so extensive a work as that of *The History of all the Branches of Experimental Philosophy*, to a Nobleman of your Grace's known attachment to the sciences, and one who has, on so many occasions, distinguished himself by his generous patronage of them. It is for the honour of any country, and of any age, in which persons of your rank and fortune chuse to appear in that character. . . ."

CHAPTER VI

COLOUR BLINDNESS

How can we hope one common faith to find,
When one in every score is colour blind?
If here on earth they know not red from green,
Can they see better into things unseen?

First Recorded Case.—The first definite record we have of a case of colour blindness dates from 1777, and is that of a shoemaker named Harris who lived at Maryport in Cumberland. His first suspicion that other persons saw something in objects which he could not see, arose when he was about four years old. Having by accident found in the street a child's stocking, he carried it to a neighbouring house to find the owner; he observed the people called it a red stocking, though he could not understand why they gave it that name, as he thought it completely described by being called a stocking. The circumstance, however, remained in his memory, and together with subsequent observations led him to a knowledge of his defect.

He observed also that, when young, other children could discern cherries on a tree by some pretended difference of colour, though he could only distinguish them from the leaves by their difference of size and shape. He also observed that by means of this difference of colour they could see the cherries at a greater distance than he could, though he could see other objects at as great a distance as they, when the sight was not affected by the colour.

He had two brothers who were afflicted with the same defect and two other brothers and sisters who, as well as the parents, were quite normal. One of these brothers when shown coloured ribbons called a light green "yellow," but he was not

very positive ; he said, " I think this is what you call yellow." Of an orange yellow he spoke very confidently, saying, " This is the colour of grass ; this is green."

Dalton.—A celebrated case of colour blindness was that of the famous chemist, John Dalton, who founded the atomic theory of modern chemistry. For a time the defect was called Daltonism after him, especially on the continent, but there was a strong feeling in this country against remembering our distinguished fellow-countryman by his defect, so on the initiative of Sir David Brewster the name " colour blindness " was adopted instead.

Dalton was first distinctly convinced of his peculiarity of vision in 1792, when he was 26 years of age, by the discovery that the flower of a geranium which appeared to others pink in all lights, appeared to him blue by day, and what he called red by candle light. All his friends except his brother said there was not any striking difference in the colour by the two lights. This observation led him to examine the peculiarities of his vision ; he then found that the pure colours, red, orange, yellow, and green were practically all alike to him, and that he called them all yellow, but that he could distinguish blue and purple, and that he called these colours by the correct names. Dalton said that blood appeared bottle green to him, grass appeared very little different from red. A laurel leaf was a good match for a stick of sealing wax.

Inheritance of Colour Blindness.—It will be noticed that Dalton's brother as well as Harris's two brothers were afflicted with the same defect as themselves. This is typical. With a healthy subject colour blindness is congenital and hereditary. It occurs in families, usually skipping a generation, and there is no way of curing it. It occurs much more frequently with men than with women; five per cent. of men are usually assumed to be colour-blind and only two in a thousand women. The data with reference to colour blindness are, however, not very accurate ; we have tested the colour vision of two thousand students at Glasgow, and it is doubtful whether true cases of congenital colour blindness occur among women at

all. The inheritance of colour blindness takes place in a very remarkable manner. If a man is colour blind, it is said that his children do not show colour blindness nor do the sons of his sons. It appears only in the sons of the daughters. In its mode of inheritance colour blindness is parallel to the peculiar pathological condition known as *haemophilia*. The blood of " bleeders " as those afflicted with this condition are called, for some unknown reason does not coagulate ; consequently they bleed profusely and continuously from even the slightest wound. Only men are affected, and the condition is transmitted only to the sons of their daughters. Or in other words the condition affects only the male, and is transmitted only through the female.

Dangers of Colour Blindness.—One of the chief symptoms of colour blindness is a liability to confuse red and green. Now red and green are precisely the colours of the signal lamps on the railways, and of the lights of ships at sea. If the engine driver or the ship's officer mistakes the lights, a very serious disaster may occur ; consequently men desirous of entering these occupations must pass an examination in colour vision. It is not such a simple matter to detect colour blindness as would be anticipated. Most men who fail in the tests are previously unaware, that there is anything seriously the matter with their colour vision. In the Report on the Sight Tests used in the British Mercantile Marine for the year 1910, for instance, it is stated, that out of 7252 candidates examined, 141 failed in the colour vision test, and that 69 of the latter were re-examined on appeal, of whom 29 passed and 40 failed. So eventually 112 failed out of 7252 or about 1½ per cent. These men were unaware of their defect, or they would have chosen another career.

It is not the bad case who is dangerous. He is easily detected. It is the half and half case, the man who recognises the signals when they are near, but who makes occasional errors when he is tired, when he has perhaps been on duty all night, and is looking at the signals through a mist or a wet glass. Such men sometimes complain bitterly when they are failed ; although they have difficulty with red and green,

they may be decidedly better than the average at distinguishing tints of blue and green.

It should be stated emphatically, that it is not a case of not knowing the names for the colours. Most men do not know for example, what tints are referred to by puce, magenta, lilac, tango red. But they have no difficulty in recognising these colours when they see them ; if they were shown one of them, told to remember it, and asked to pick it out of a bundle of assorted colours a day or two later, they would have no difficulty in doing so. The colour blind do not see the differences between the different colours, or they see only slight differences which disappear altogether when the light is bad. Why they should be unaware of their defect, it is difficult to say. The distinguished chemist Dalton who was a very bad case, as has been mentioned above, did not find out his peculiarity until he was 26 years of age. This is all the more remarkable, as he must have had to deal with coloured salts. Possibly it is a case of not observing from excess of familiarity what is directly before one's nose. Or the colour blind may think that they are right and everyone else is wrong. Some time ago I tested the colour vision of a cheerful youth who was wearing a new overcoat of a colour which could only be described as a cross between fawn and salmon pink. After the test was over and he was found to be abnormal, I asked him if he ever had differences with his friends about the colours of objects. "Yes," he said, his mother asked him why he bought a pink overcoat. "And what did you say to that," I asked. "Oh," he said, "my mother does not know much about the colour of overcoats."

Theories of Colour Vision.—It has been shown in the preceding chapter, that nearly all colours can be reproduced by adding the three primaries, red, green, and blue in varying proportions. This fact underlies the colour triangle, and is beyond all dispute ; it is accepted by all theorists, and is the basis of various systems of colour photography. But three authorities on the subject, Young, Helmholtz, and Maxwell, made the additional assumption that there are three primary colour sensations corresponding to these primary

colours ; this is the fundamental hypothesis of the Young-Helmholtz theory of colour vision, and it has been a subject of debate for years.

Put in its simplest form the Young-Helmholtz theory states, that in the retina of each eye there end three sets of nerves, one set for the sensation of red, another for the sensation of green, and a third for the sensation of blue. When red light falls on the eye, it stimulates the red nerves. When yellow light falls on the eye, it stimulates both the red and green nerves. When white light falls on the eye, it stimulates all three sets of nerves. The colour blind lack either one or two sets of nerves. If they lack two, they are totally colour blind, and are referred to as monochromats. If they lack one set, they are referred to as dichromats ; all the commonly occurring cases are dichromats who lack either the red or green set of nerves, and are consequently referred to as red or green blind. Observers with normal colour vision are referred to as trichromats.

One objection to the Young-Helmholtz theory is that there is no anatomical evidence for the three sets of nerves, but the most serious objection is, that the colour blind do not fit into the original classification. I have tested carefully some thirty colour blind individuals, and not one of these agreed with Helmholtz's typical cases. Helmholtz became aware of the inadequacy of his earlier views, and before his death he modified his theory so as to make it better able to take account of the cases occurring in practice. But when the theory is modified, it loses its original simplicity and force.

The other theory most prominently before the public at present is the non-elemental theory which has been advocated by Dr. Edridge-Green for the past twenty years. According to this theory there are no elementary sensations ; colour vision occurs in all degrees of goodness passing in insensible gradations from the totally colour blind through the normal to those who have better colour vision than the normal, and the colour blind should not fall into classes like the red-blind and green-blind.

It should be stated that the mathematical development

of Helmholtz's modified theory does equally well for the non-elementary theory, so that there is no serious difference between the two standpoints ; the current practice of identifying Helmholtz's name with his earlier view is hardly fair to his memory, in consideration of the great advances he made in the study of the subject.

Tests for Colour Blindness.—Formerly the Board of Trade employed a test for colour blindness known as Holmgren's test, after the name of a Swedish professor who first introduced it. The candidate undergoing this test was given a heap of over a hundred skeins of wool of different colours and different degrees of saturation, amongst which were reds, yellows, greens, blues, browns, bronze, fawn, greys, purples, pinks, etc., together with three test skeins, a very pale green, a pink and a red. He was first asked to pick out of the heap all the skeins which appeared to him to be of the same colour as the green test skein, keeping to the one colour but taking tints both lighter and darker than the test colour. He was then asked to select colours which matched the second test skein, and finally to select colours which matched the third test skein. The colour blind man made wrong matches, for example, the pale green might be matched with drab, bronze brown and fawn, the pink with reddish grey and blue green, and the red with brown and greenish yellow. Holmgren was a supporter of the Young-Helmholtz theory, and as a result of the test the candidates who failed were classified as wholly or partially red or green blind. If they matched red with dark colours they were supposed to be red-blind ; otherwise they were green blind. If they made bad mistakes, they were wholly red or green blind ; if their mistakes were not so serious, they were only partially red or green blind. With the wool test anyone found to show any evidence of colour blindness was rejected. According to Dr. Edridge-Green the wool test allowed 50 per cent. of dangerously colour blind to pass and 50 per cent. of those rejected by it were not dangerously colour blind.

One popular objection has always been made against the wool test, namely that the examination is not made under the conditions which occur in practice. The candidate is not

qualifying for a position in a wool store, but must recognise red, white, and green lights rapidly under difficult conditions. So there is no doubt that the test at present in use, the lantern test, is a great improvement. The candidate undergoing this test is taken into a dark room in which there is a dark lantern provided with apertures of different sizes. Coloured glasses can be rotated behind these apertures, and the apertures appear the same size to the candidate as the signal lights in ordinary practice. The candidate is simply asked to name the colours shown him. The standard of attainment set up by the Nautical Advisers of the Board of Trade is, that the candidate should be able to distinguish between the red, green, and white signal lamps at a distance of one mile.

There are other ways of testing colour vision, some of a much more exhaustive nature than the two methods above described. They do not always lead to consistent results; the individual tested sometimes does very much better under some tests than others. Thus it is desirable, that he should be tested as nearly as possible under service conditions, and there is no doubt that the lantern test fulfils this requirement.

The Bead Test for Colour Vision.—Fig. 49 depicts a very useful and rapid method of detecting colour blindness introduced by Dr. Edridge-Green under the name of "The Bead Test for Colour Vision." The arrangement consists of a box with four compartments, each with a separate hole, and a number of coloured beads which are shown in the open drawer. The four holes are labelled respectively red, yellow, green, and blue. The man under examination is told to pick out all the red beads, and put them in the hole labelled red. He then goes through the same process with the other colours; once a bead is dropped through the hole, it is lost from view, and cannot be used for purposes of comparison. The beads that are neither red, yellow, green, nor blue, are left in the drawer. When the test is finished, the examiner lifts off the top of the four compartments, and sees what sort of a selection has been made.

The bead test is very effective in the hands of a capable examiner. The manner in which the beads are selected is

quite as important as their final resting place. If the candidate hesitates long with a pink bead on the edge of the blue hole, he is obviously not normal, even if he gets it right in the

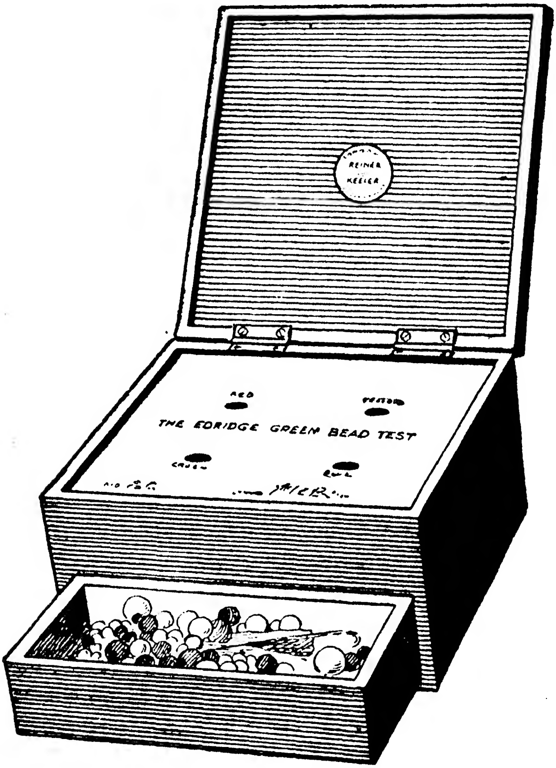


Fig. 49.
(*From The Royal Philosophical Society of Glasgow.*)

end ; and if he ignores all the bright colours, and commences by putting a dirty neutral colour with a reddish tinge in the red hole, there is also something wrong.

The bead test reveals not only colour blindness, but differences in the classification of colours. Some people are very particular, and put only a pure red in the red hole ; others include pink and crimson under red, and a few are inclined to extend the term to include brown and amber. Usually out of four men two put peacock blue in blue and one puts it

in green, while the fourth leaves it in the drawer. Three out of four women put peacock blue in blue. Such differences interest the people using the test very much ; in fact I have heard the apparatus called " The Parlour Game Test for Colour Vision," and it is really more interesting than many parlour games. In using it the examiner must distinguish between a selection made because the examinee sees the colours different and a selection made because he classifies them differently ; this is, however, easy.

Tobacco Blindness.—Colour blindness may develop in a man originally normal as a consequence of disease of the retina or optic nerve, or as a result of some affection of the brain. Acquired coloured blindness of this kind is sometimes produced by heavy smoking, and is usually accompanied by indistinctness of vision, at least in the centre of the field. The disease is a progressive one, and at first is generally unrecognised, the deficiency of vision being slight ; then the sufferer becomes unable to read, and finally cannot see the letters at all. The following interesting paragraph quoted by Dr. Edridge-Green, and taken from the *Shipping and Mercantile Gazette and Lloyd's List* of June 29, 1881, illustrates the dangers of acquired colour blindness.

" Colour Blindness, New York, June 8th.—The pilot of the steamer *City of Austria,* which was lost in the harbour of Fernandia, Florida, last April, is proved to be colour-blind. In this it would appear that he mistook the buoys, and his mistake cost the owners 200,000 dollars. An examination showed that at a distance of more than six feet, he could not distinguish one colour from another. The physicians attribute the defect to an excessive use of tobacco."

A single initial test is no guard against colour blindness of this type ; periodical examination is necessary.

How the Colour Blind Reveal Themselves.—Most boys who know they are colour blind are sensitive about their defect, and try to conceal it, for fear of the ridicule of their companions. Also I have come across two recent cases in which boys were punished by school teachers who ought to have known better, for using colour names wrongly. And men in later

life may think that if it was known they were colour blind, people might believe they were unable to do their work properly ; this applies to occupations in which colour enters to only a slight extent, for example, a works chemist. So amongst the circle of one's acquaintances there may, unknown to one, be several to whom the colours of common objects appear very different. The relativity of colour is of much more practical importance than Einstein's relativity of space and time. In the crowd waiting at the street corner for the tramcar there may be a man who cannot tell a blue car from a green one, or who classes white, yellow, and green cars as all one colour. Such people, however, often reveal themselves by little eccentricities of dress, for example, by wearing neckties of peculiar colour. Also in the picture galleries the artists who are partially colour blind get the colours wrong ; a yellow next a green is often painted red, and a yellow next a red is often painted green. And strange, as it may seem, there is at least one well attested case where a colour blind artist acquired a reputation as a colourist. So the Philistines who scoff at new interpretations of nature may have at times some justification.

But the artists must not be taken too literally. One of the Scotch railway companies got out a very attractive poster with some such motto as " In winter the hills of the Scottish lowlands are green to the very top " and a view, presumably, of the same hills, with their tops a fine purple. This is not colour blindness but art.

CHAPTER VII

COLOUR PHOTOGRAPHY AND STEREOSCOPY

THE artist has a wide range of colours at his disposal, while the photographer is restricted to one colour. It is true he has a choice of colour; his print may be black, or sepia, or brown, or, if he uses the carbon process, any colour whatever. But he can use only one colour for one print. This has always seemed a limitation to him, and ever since the beginning of photography there have been attempts to find a simple means of photographing objects in their natural colours. These attempts have been only partially successful.

Before describing them, however, it may be questioned if it is desirable for one art to imitate another. Photography is by no means an automatic process; in the composing of a picture, the arrangement of the lighting, local development, the possibility of modifying the print during enlargement, etc., there is ample room for originality and taste as well as for technical skill. In our climate colours are subdued. In a city street the only patch of bright colour may be a red letter box. It is possible that a large sepia monochrome with one or two tints laid on by hand may give a more truthful rendering of such a scene than the frequently somewhat garish production of the picture gallery. In any case there is an increasing number of people who think it does. Consequently it is possible, that in looking for a simple process of colour photography the photographer has been seeking for something that he does not really want; if he got it, it would be a novelty and a technical triumph, but probably would not find general use.

Methods of colour photography can be divided into two classes, those which use one surface for all the colours and those

which employ one picture or negative for each of the three primary colours.

Lippmann's Process.—About 1810, thirty years before Daguerre and Fox Talbot put photography on a practicable basis, T. J. Seebeck discovered at Jena, that when silver chloride was exposed to the solar spectrum after a preliminary exposure to light, the red rays produced a rose coloured substance, the blue rays a blue substance, and the violet rays a reddish brown substance sometimes akin to violet. This led immediately to a great amount of experimenting by other investigators. It was shown more than eighty years afterwards by O. Wiener, that in Seebeck's experiments it was the subchloride that was the sensitive substance, that the colours produced were actually pigmentary, but that they were not very like the colour of the light producing them ; also they could not be fixed. Hence it is improbable that work on this line will lead to any useful result.

But one of the early workers, Edmund Becquerel, who repeated Seebeck's work, varied the conditions of the experiment. A film of silver chloride was formed on a silver plate by the electrolysis of dilute hydrochloric acid, using the plate as electrode. When the film was exposed to bright colours, it sometimes reproduced them quite well. This success was due to the fact, that the sensitive film was backed by a silver plate. Becquerel thus unwittingly employed the principle of stationary waves, a principle which was afterwards applied with very great success to the photography of coloured objects by Prof. Gabriel Lippmann of Paris in 1891. We shall explain what this principle is :

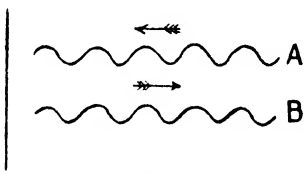


Fig. 50.

Let A represent a light wave travelling towards a silver mirror on the left, B the same wave after reflection. The wave returns along the same path by which it approached, and consequently the waves should superimpose, but to make the diagram clearer the returning wave is shown below the approaching one. Now when two equal

waves going in opposite directions superimpose, they produce what is called a stationary wave. Figs. 51 to 55 exhibit successive phases of a stationary wave; after 55, it changes back through the same phases in the reverse order to 51 again. The cycle is then repeated. At certain points called nodes and denoted by N there is no displacement; at other points called loops and denoted by L the wave goes from crest to trough and back again. The wave is said to be stationary, because it does not progress as a whole; the crests keep on appearing and disappearing at the same points.

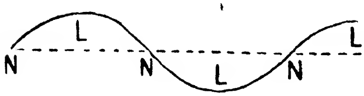
Fig. 51.


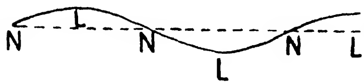
Fig. 52.


Fig. 53.

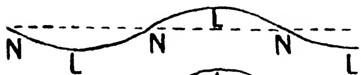
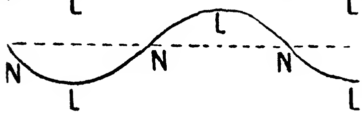

Fig. 54.


Fig. 55.


If a wave is reflected perpendicularly from a mirror MM as shown in the plan (Fig. 56), loops are formed on the dotted lines at distances $\frac{1}{4}\lambda$, $\frac{3}{4}\lambda$, $\frac{5}{4}\lambda$, $\frac{7}{4}\lambda$, etc., from the mirror. These loops are planes of maximum photographic action; at the nodes there is no photographic action.

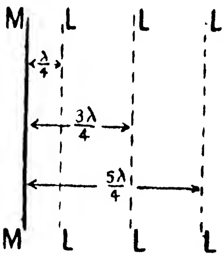


Fig. 56.

Lippmann prepared plates with a photographic emulsion of exceedingly small grain which was sensitive to all the colours of the spectrum, and exposed it in a dark slide constructed to hold mercury. The glass side of the plate was turned towards the light, while the mercury pressed against the other side and formed the reflecting surface. Stationary waves were produced, and thus after development the film consisted of a great number of equidistant planes, all parallel to the mercury surface and distant $\frac{1}{2}\lambda$ from one another. The

thickness of silver in each plane was so small, that they were partially transparent.

Suppose now, that white light is incident on this system of planes; then each plane gives rise to its own reflected wave. If we consider the different constituent colours of the white light separately, the reflected waves reinforce one another in the case of that colour for which half the wave-length equals the distance between the planes. For all other colours the reflected waves interfere and destroy one another. Thus when the plate is viewed normally in white light, each part of it appears in the colour of the light to which it has been previously exposed, and the whole plate gives an image of the original object in its natural colours.

Microscopic sections of the films have been prepared and the reflecting surfaces rendered visible to the eye. Lippmann's process is not easy to carry out; one great difficulty is to ensure that the film when finished will be in the same condition as during exposure, and that the distance between the silver deposits in the finished plate will be the same as between the loops of the stationary wave. Consequently the process has been little used. But it probably never will be improved upon as a method of photographing the colours of nature directly as they are.

The Three Negative Processes.—All the methods of colour photography in commercial use are of the nature of a compromise. They do not seek to represent the colours exactly as they are, *i.e.*, by the same wave-length, but by a colour which cannot be distinguished from the original colour by the eye, although it may be distinguished from it by the spectroscope. They are founded on the fact explained in Chapter V, that nearly all colours can be reproduced by adding red, green, and blue lights in varying proportions.

In taking an ordinary photograph the picture is focussed on the plate in the camera, and the plate is then exposed, developed, and fixed. The picture produced in this way is called the negative, because, when it is held up to the light, it gives the rendering of light and shade reversed. The parts of the picture which should come out light are dark; the

sky, for example, comes out black, so do white collars, while boots come out white. Now in the case of an ordinary photograph both visible light and invisible rays fall upon the photographic plate, red, green, and blue visible light, and ultra-violet invisible rays. But the ordinary photographic plate is sensitive only to the ultra-violet, the blue, and partly to the green. It is not sensitive to the red; consequently red letters on a dark background do not come out at all on the negative. It is because the plate is not sensitive to red, that it can be developed in a red light. The single negative obtained in ordinary photography is produced by ultra-violet, blue, and some green rays all superimposing on the plate and giving a joint picture. The methods of colour photography in commercial use all replace this single negative by three separate negatives, one produced by each of the three primary colours, red, green and blue.

The plates employed must be sensitive to red and green as well as to blue. So-called orthochromatic plates are unsuitable; they, like Kodak and Ensign film, are fully sensitive to the green but not to the red. Luckily it was discovered by Prof. H. W. Vogel in 1873, that when plates are bathed in certain dyes, they are rendered sensitive to the red and even if necessary to the infra-red. Plates sensitized in this way to the whole spectrum are now put on the market by different makers, and they alone are suitable for colour photography. As they are sensitive to red, no red lamp can be used in the dark room. The plates must be developed in darkness or by a very faint green light; the latter is employed on the principle that if a light *must* be used, it is best to employ the light which gives most illumination in proportion to the damage it does the plate.

The three separate negatives may be taken (*i*) with an ordinary camera one after the other. In this case neither camera nor object must move during the three exposures. Or (*ii*), the three separate negatives may be taken simultaneously by means of a special camera provided either with three lenses or with an arrangement of mirrors. Or (*iii*), by means of a screen plate the three negatives may be taken

simultaneously on the same plate with an ordinary camera; this is the method employed in the Lumière and Paget processes.

Method used in Three-colour Printing.—The first method is probably the easiest to understand, so we shall describe it first. A quarter-plate camera, for example, is set up before a vase of flowers, and a red filter, a sheet of coloured gelatine contained between two glass plates that transmits only the red rays, is placed in front of the lens. Then an exposure is made. Next the plate is changed, a green filter placed in front of the lens, and another exposure made. Finally the plate is changed again, a blue filter placed in front of the lens, and another exposure made. We thus obtain three negatives, one made by each of the three primary colours. Now let a glass positive be made from each of these negatives, and let these positives be used as lantern slides and projected on a screen by three separate lanterns, each in the colour in which the corresponding negative was originally taken. A positive is a negative made from a negative, and consequently has the correct rendering of light and shade. The arrangement of lanterns is similar to the one described in connection with the mixing of colours, only instead of projecting three discs of light we are projecting a red, a green, and a blue picture. If now the red, green, and blue pictures are superimposed, we shall have a picture of the vase of flowers on the screen in approximately its natural colours. This is referred to as the additive process of reproducing the colours.

Again, if we prepare half-tone blocks from each of the three negatives, and make impressions of these blocks on a sheet of paper, each in the colour complementary to the filter through which the corresponding negative was taken, *e.g.*, the impression from the block made from the negative taken through the red filter is in peacock blue, then we shall have a print on the paper of the vase of flowers in its natural colours. This is the method employed in commercial three-colour work. It is referred to as the subtractive method of producing the colours. It is exemplified in the colour plate facing p. 6; here we have first of all the three complementaries, then the three

primaries formed by printing them two and two together. In reproducing the green patch, for example, it would appear black on the green filter negative and clear on the red and blue filter negatives. It is consequently printed by the blocks made from the latter two negatives, in the colours respectively complementary to the taking filters for these negatives, *i.e.*, in yellow by the blue filter block and peacock blue by the red filter block; these colours superimposed give green.

Transparencies can be made by this method by preparing carbon prints in yellow, crimson, and peacock blue, corresponding to the three impressions in colour printing, and cementing these prints together. Thus the picture can be projected in colours by a single lantern.

When the three negatives are taken simultaneously, there is no difference in principle or procedure from the case in which they are taken one after the other.

Lumière and Paget Processes.—The Lumière screen plate is an ordinary colour-sensitive plate covered with a layer of flattened starch grains. These grains are transparent, are coloured red, green, and blue, and are well mixed over the whole surface of the plate. The grains act as filters. They are invisible to the eye, but can be seen on examining the plate with a microscope. It does not matter where the filter is, as long as it comes between object and image. In the arrangement previously described it was in front of the lens; here it is on the plate. The light cannot get to the silver salt without passing through a filter. All the parts of the plate behind the red grains form a negative similar to that taken through the red filter in the method previously described. Only here the negative, instead of being continuous, forms a mosaic; it is mixed up with pieces of the other two negatives, and the area of each is less than one-third of the area of the plate.

After exposure the Lumière plate is developed and reversed. The image in the emulsion is converted into a positive by treating it with special solutions. The same plate that was the negative becomes the positive. We obtain, therefore,

one plate which is a combination of the three positives produced by the method previously described. They are in the form of a mosaic, all mixed up. If this picture is put in a lantern and projected, it gives a picture of the original object in its natural colours. If it is held up to the window, it acts as a transparency giving a picture of the object in its natural colours. But there is no easy way by which it may be converted into a coloured print on paper.

The Paget method differs from the Lumière method in having the screen on a separate glass plate from the sensitive plate ; consequently one screen may be used with a number of plates in succession. The screen is covered with little red, green, and blue rectangles forming a geometrical pattern. It appears colourless to the eye, but the rectangles can easily be seen under the microscope. They are much larger than the starch grains in the Lumière screen. The screen is held in the slide with its surface in contact with the plate. After the plate is exposed, it is developed, fixed, and a glass positive made in the usual manner. This glass positive is then combined with a screen, similar to that through which the original exposure was made. The screen and positive must be carefully adjusted, so that they are accurately in register. Each part of the positive must be opposite a rectangle of the same colour, as the exposure of the corresponding part of the negative was made through. When positive and screen are combined in this manner, they form a coloured transparency which can be viewed by holding it up to the window, or which may be projected as a lantern slide. There is no easy way of converting this transparency into a coloured print on paper.

Anyone possessing a camera that takes one of the standard sizes of plates can make coloured transparencies by either the Lumière or Paget process at relatively small expense, and many amateurs have experimented with these processes, though few have carried them very far.

Cinematography in Colours.—The most interesting developments of colour photography are at present taking place in cinematography. Here it is no disadvantage not to be able to obtain a coloured print, and three lenses are not necessary

to project the three coloured pictures. One lens can project all three one after the other so rapidly, that they fuse into one. Similarly the three pictures can be taken in rapid succession by the same lens, and the elaboration of apparatus and difficulties of registration can be avoided. So the prospects of success are greater in this field. One highly successful method, Kinemacolor, uses only two negatives; this does not give such an accurate representation of the colours, but it enables the pictures to be projected at two-thirds of the speed.

The processes of colour photography based on the primary colours are still in course of development. Here it has been possible to give only an outline of the subject; in the British Journal Photographic Almanac, those interested will find references to investigations being carried on at present. In a field like this textbooks rapidly become out of date; one learns more from the scientific journals and the price lists supplied by the dealers in the subject.

Colour Contrast in Monochrome.—Colour filters and plates sensitive to the whole visible spectrum are not restricted in their use to three colour photography; they are often employed with great effect in monochrome.

Most amateur photographers know, that when a landscape is photographed on an ordinary plate, the green and the foliage of trees come out too dark, because such plates are only slightly sensitive to green. If orthochromatic plates are used, the greens come out lighter, and the improvement is more marked if a pale yellow filter is fitted in front of the lens; such a filter cuts out the ultra-violet and some of the violet, which have a great action on the plate though they make little impression on the eye. But even with a filter and orthochromatic plates, which reach to the yellow of the spectrum, all the objects in the picture do not appear as bright as they ought to do; red poppies in a field still come out black. To give them their true value, plates sensitive to the red, spectrum plates or panchromatic plates, as they are called, require to be used.

All the objects in the picture then receive their proper light value. But this is not always advisable. To return to the

case of the poppies; they may be exactly as bright as the grass round about them, but they stand out from the grass owing to their difference in colour. Now the ordinary photographic plate has no means of rendering difference of colour. If the poppies and the grass both receive their proper light value, they are represented by the same shade of grey on the plate and the poppies consequently do not stand out from the background at all. It is better in this case, therefore, to use a plate not sensitive to red, make the poppies come out black, and use light contrast as a substitute for colour contrast. But this is an exceptional case; if we were photographing a steamer which had red funnels with black tops, red sensitive plates would effect a great improvement; they would make the funnel light grey with a black top, whereas ordinary plates would make the whole funnel one uniform black. In correcting the tendency of the plate to overvalue the blue end of the spectrum the photographer must not proceed blindly but study the requirements of his subject.

Colour correction is especially valuable in dealing with distant hills, the grain of wood in photographs of furniture, and in portraiture where freckles are concerned. Distant hills are generally hazy; this is due to the scattering of light by water vapour in the atmosphere. The violet end of the spectrum is scattered most, consequently the photographic plate accentuates the haze, and must be corrected by a yellow filter. The grain of a polished piece of wood comes out in a surprising way with red-sensitive plates and a yellow filter. Freckles appear black when viewed under blue or violet light and are much accentuated if photographed in the ordinary way; they can be rendered less noticeable by correcting for colour, though the photographer has other methods of getting rid of them.

An Optician's Dream.—Recently in a certain revue at a London theatre the lighting was changed from red to green in one of the scenes; this produced striking changes in the costumes of the actors. For example, one man was wearing a suit of evening dress made of red cloth with black trimmings. Under the green light it seemed orthodox evening dress;

under the red light it was red faced with black. The black changed to red immediately the electrician pulled over the switch. In the same way the similitude of relief which is obtained by shading on a flat surface can be altered. Similar effects of this nature had been obtained previously, but the colours available are not pure enough to allow of their being much used.

The above achievement, however, pales before the ideal of a writer in *Everyday Science*.—The great advantage of a newspaper over the cinematograph palace is, that the reader can select what he wishes to read, and ignore the remainder. But at the cinematograph he must take everything. We all know the unfortunate plight of the man who attends only to see a special film, a boat race for example, who sees the last few feet of the boat race as he goes down the passage to his seat, and then has to sit through a drama in six reels, an American comedy, and an educational film, before the boat race comes round again. The article in question proposes to change all this:

"When you enter the auditorium you see upon the screen what appears to be a hopeless wild jumble of figures, scenes, and colours—the whole an indistinguishable blur. At the side is an illuminated programme on which the items are numbered. Ignoring the screen, you select an item, note its number, and then on the ledge in front of your seat you find a little lever with a row of numbered slots. You move the lever to the number you have selected. A catch is released and a box appears from the slot. This contains a pair of coloured spectacles; you don them, and behold, the blurred medley of shapes and colours on the screen resolves itself into one ordinary film, the film whose title you choose from the programme. The secret is simple. Four or five films are projected simultaneously on to the same screen, but each film is coloured in a single colour, distinct from the others, and by wearing glasses that admit only the rays of that colour, all the other pictures in the other colours become invisible to you, while your particular picture appears to you in the blacks and greys of the ordinary film of to-day. Each goes

on over and over again. As soon as you have seen one, all you have to do is to choose again, move the lever, and don another pair of coloured spectacles, so that if your tastes are for comedy and melodrama, you don't have to sit and wait through the sob-story and the travel pictures."

Something of the above nature might certainly be attempted at present. But owing to the colours not being pure enough bits of the one picture would constantly appear in a faint but nevertheless very disconcerting manner on the top of the others. And the picture selected would not appear in the blacks and greys of the ordinary film, but in the same colour as the coloured spectacles. So the project as described is but a beautiful dream.

The Stereoscope.—Another problem has captivated the optician's imagination almost as much as colour photography, and that is the problem of stereoscopic projection. The pictures at the cinematograph are projected upon a flat screen ; no one would be misled into thinking, that the actors depicted are solid figures moving upon a stage. It is true that if the photographer has known his business, the light and shade in the picture may give an impression of relief, but no one would ever mistake it for the real thing. Shall we ever obtain such an effect of solidity on a flat surface, that looking at a picture will be like looking through a window, the figures and objects taking different positions relative to one another according to the angle from which the observer views them ? Then the final goal of the optician will be achieved, and it will be impossible to distinguish the picture from the reality. Some progress towards this goal has been made, and there already exists a theoretical solution. We shall proceed to explain how the matter stands at present.

The appearance of solidity that objects have, is due mainly to the fact that we have two eyes. These eyes are situated about two and a half inches apart in the head, and consequently the pictures seen by them are not exactly the same. If, for example, we look out of a window, keeping the head fixed, closing first the one eye and then the other, the bar of the window moves relatively to the background. Seen with the

one eye it is superimposed upon a certain object outside the window, seen with the other eye it is superimposed upon another object. The brain fuses these two pictures together, by combining the right hand portion of the picture seen with the right eye and the left hand portion of the picture seen with the left eye. The two eyes must see different pictures in order to get a sensation of solidity. If we look at an ordinary photograph, the pictures seen by both eyes are exactly the same; consequently we have a sensation of flatness and the objects do not stand out in relief.

The stereoscope, which can be purchased for a few shillings, is an instrument for viewing photographs in relief. It consists simply of a holder for carrying two photographs of the same view taken from slightly different standpoints and mounted side by side, and two spectacle lenses in a wooden frame for viewing them. Each of the lenses produces a virtually enlarged image, and also acts as a prism and deviates the rays. So the pictures though mounted side by side really appear in the same place, each eye sees it own picture, and the objects depicted have a wonderful appearance of solidity.

Photographs for use in a stereoscope are usually taken with a special camera which has two equal lenses mounted a short distance from each other side by side. If moving objects are to be photographed, a camera of this nature is a necessity. But in the case of stationary objects an ordinary camera is sufficient; it is only necessary to take one picture, then move the camera a few inches to the side and take another one. The two pictures are mounted side by side the proper distance apart. The making of stereoscopic pictures in this way is extremely easy: any amateur can do it.

Some other interesting experiments can be made with the stereoscope. If the two pictures are each divided by a vertical line, and the left hand side of the right hand picture and right hand side of the left hand picture obscured by pasting white paper over them, the operation being done very carefully so that there is no overlapping, then the relief is undisturbed; the one eye apparently dominates the one half of the field completely and the other eye the other half.

Again if the prints are dissolved off their mount and re-mounted interchanged, the relief should be reversed. The near objects should appear farthest away ; a man in the fore-ground should appear more distant than a telegraph pole in the background. As a matter of fact if the objects are isolated, we do obtain reversed relief, but there are other factors, light and shade, association of size, perspective, etc., which come into play, and the result generally is confusion.

Stereoscopic Projection.—The stereoscope is very satisfactory as far as it goes, but only one person can look into it at one time. Suppose we projected the two pictures on the top of one another on a screen, then if each eye saw its own picture, all would be well, and every spectator would get the stereo-scopic effect simultaneously. But the difficulty is that each eye sees both pictures blurred on the top of one another. Various methods of overcoming this difficulty have been suggested. One method is to project the two pictures in different colours, and supply each spectator with coloured spectacles, the colour of each glass being the same as of the picture for the other eye. For example, suppose the picture for the right eye were drawn in blue lines and the picture for the left eye in red, both superimposed on one another, then the right eye looking through a red glass would see its picture in black on a red ground and the other picture either not at all, or at most very faintly, whereas the left eye looking through a blue glass would see its picture in black on a blue ground, and the other picture not at all or very faintly.

Another suggestion is to throw the two pictures in succession on the screen by a cinematograph. The principle of the cinematograph is, of course, that a series of pictures each slightly different from its predecessor is thrown upon the screen so rapidly, that they fuse together. According to this scheme the first, third, fifth pictures would be for the right eye, the second, fourth, sixth . . . for the left, and each spectator would be provided with goggles fitted with shutters which opened and closed automatically in time with the pictures on the screen. The right eye shutter would close when the left eye picture was on, and *vice versa*. A third

suggestion is to use polarised light and fit the two eyes with polarising prisms set at right angles to one another.

All these methods are, however, too costly and elaborate for practical use. No method which involves fitting anything to the eyes of the spectator has a chance of success, so attempts on the problem have been made from other sides. One of these, exhibited under the name of Kineplastikon, was a variant of the old illusion known as Pepper's ghost; Prof. Pepper was an illusionist who travelled about the country exhibiting the ghost.

Pepper's Ghost and Kineplastikon.—Pepper's arrangement is sometimes used on the stage for producing ghosts, *e.g.*, in the ghost scene in *Julius Caesar*. Fig. 57 is a plan showing how it is done in this case. FF are the footlights, BB the back of the stage, and AF is a large plane sheet of glass which is placed vertical and at an angle of 45° with the line of vision of the the spectators. S is a solitary spectator seated in the middle of the stalls. G is the actor who is to fill the rôle of the ghost. He is too far to the side for S to see him directly, but S sees him by reflection in the glass apparently at G′; *i.e.*, the rays of light from G to S traverse the actual path GCS, but appear to traverse the path G′CS. The rest is merely a matter of lighting; the background BB is dim, and the actor G is at first kept dark, but, when his time comes, the limelight is turned on him, and he duly "appears" at G′. His image is, of course, transparent; bright parts of the background can be seen through it.

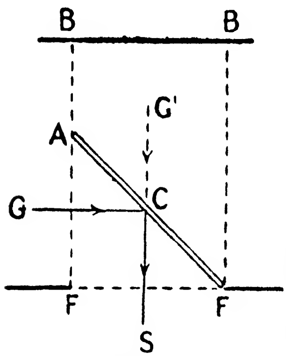


Fig. 57.

The disadvantage of the arrangement is that it requires a deep stage and a very large glass plate. For this reason the ghost is made to appear inside the tent; the glass requires then only to stretch across the tent, not across the stage.

In Kineplastikon the actor G was replaced by a screen on

which a cinematograph played from the side of the stage. When a cinematograph is played upon a cloth screen, the pictures are equally visible from the front and the back. The films were apparently specially made with light figures and a very dark background; the figures consequently appeared to move in a plane through G′ parallel to BB but in front of it. It would have been quite feasible to play another cinematograph from the back on a screen at BB. We would thus have a picture in two planes, and the objects in the first plane would stand out in relief from the objects in the back plane. But the method would be suitable only for very special subjects; it could not represent a man walking from the back to the front of the stage.

Lippmann's Integral Photography.—Prof. G. Lippmann, who brought to perfection the interference method of colour photography, has also invented a method of photography in relief. The objects in a photographic print produced by this method stand out in relief, and the appearance of the picture changes according to the angle from which it is viewed. No auxiliary apparatus is necessary, and several spectators can view the print at the same time. Theoretically the method is a complete solution of the problem; looking at the picture is like looking through a window or at figures on a stage, so great is the sensation of solidity. But the photographs must be taken and the prints must be made upon glass plates of an extremely elaborate nature, so elaborate that it seems at present, as if the method would remain only of theoretical interest.

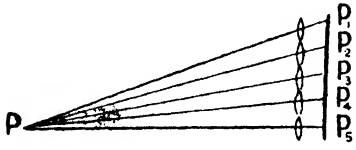


Fig. 58.

These plates are modelled upon the eye of an insect. The human eye has one lens which focusses a single picture on the retina, but the eyes of flies and other insects contain very many lenses, all arranged side by side, each forming its own picture. These pictures are slightly different from one another, since the lenses do not all occupy the same position relatively to

the object. Fig. 58 represents one of Lippmann's plates. P_1P_5 is the sensitive surface; in front of the latter a large number of similar small lenses is arranged, each distant its focal length from the sensitive surface. When the plate is exposed to the light, each lens forms its own image, *e.g.*, separate images P_1, P_2, P_3, P_4, P_5, are formed of the point P. There are partitions behind the lenses which prevent the rays from one lens overlapping into the space behind its neighbours. The plate is really equivalent to a great number of photographic cameras. It is exposed directly to the object; no camera is necessary.

After the plate is developed and fixed, it is placed opposite a similar plate (Fig. 59), and illuminated uniformly from the back. The rays pass through it and fall on the second plate; the latter is developed and fixed, and forms the positive that corresponds to the first as negative. When the positive is viewed it gives a picture in relief of the original object.

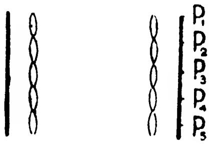


Fig. 59.

In order to understand why it should do so, consider Fig. 58. If the first plate were illuminated from the back, all the points P_1, P_2, P_3, P_4, P_5, would act as objects, and send out rays of light which would unite in forming an image at P, but with light and shade reversed. If P had been originally bright, it would now be dark. All the rays going from the first plate towards P meet the lenses of the second plate as shown in Fig. 60, and form images at Q_1, Q_2, Q_3, Q_4, Q_5. If now the first plate is removed and the second illuminated from the back, light and shade are reversed a second time, and an eye to the right of the plate sees a bright point at P. Or in other words the plate of Fig. 60 reproduces the object of Fig. 58. From the nature of the subject the explanation is

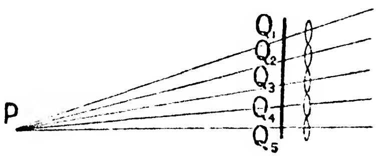


Fig. 60.

difficult and will not be understood unless the reader has a good knowledge of the properties of lenses.

The practical difficulty in carrying out the method is, of course, to make plates with a large number of small lenses and have at the same time these lenses mounted with sufficient accuracy. Lippmann verified the method by means of plates fitted with square lenses of two millimetres side.

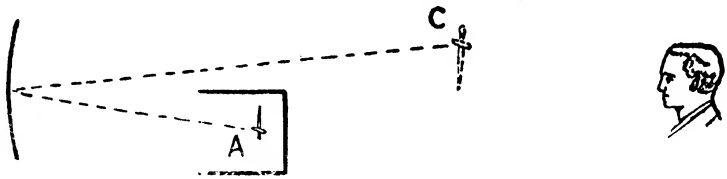


Fig. 61.

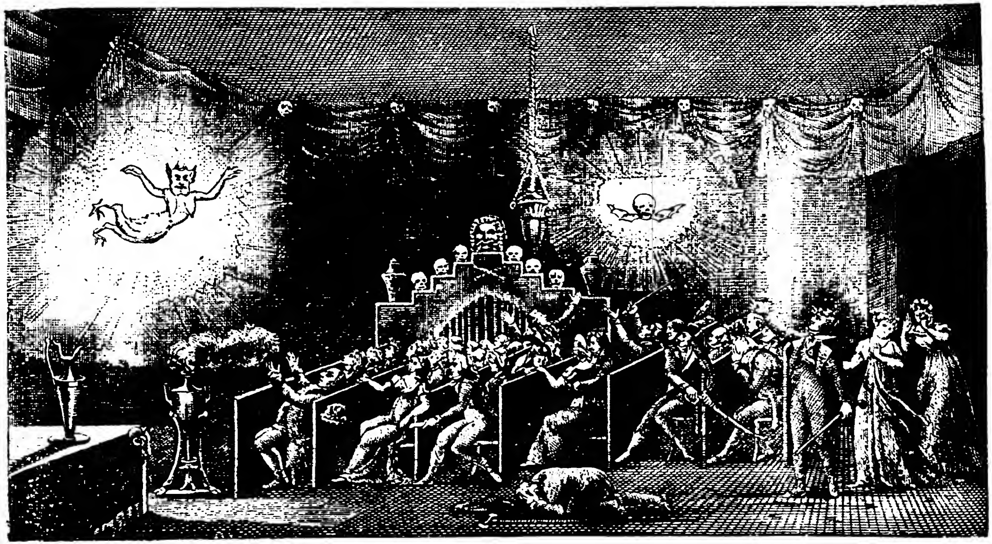
The Magic Dagger and Phantom Bouquet.—Concave spherical mirrors are sometimes used for projecting images in relief. They require a solid object, however; there is no advantage to be gained in using them with lantern slides. Fig. 61 represents an illusion known as the "Magic Dagger," in which a concave mirror is employed. A dagger is suspended at A inside a box in an inverted position. The box contains electric lamps not shown in the figure, and hence the dagger is strongly illuminated. The rays issuing from it fall upon the concave mirror at B, are reflected by the latter, and form a real erect image at C. The illusion is shown in a partially darked room; the spectator sees a luminous dagger before him, which, when he tries to grasp it, melts into thin air. Also if he moves to the side, so that his eyes do not catch the reflected rays from the mirror, the illusion vanishes. The spectator cannot see the real dagger or the lamps which illuminate it, as they are concealed by the box. The illusion is a very effective one when it is properly staged.

The "Phantom Bouquet" is another variant of the same illusion. Instead of a dagger a bouquet of flowers is suspended upside down inside the box and a vase is placed at C. When the spectator is in line with the vase and the mirror, an erect image of the bouquet appears in the vase, but when he steps to the side, the vase is empty.

An illusion of dancing human figures nine inches high that was exhibited ten or twelve years ago, also depends on the concave mirror. The figures appeared on a little stage in front of a dark curtain. The illusion was shown in a darkened room of special construction, very narrow at the end where the figures appeared and broad at the other end; thus all the spectators got some of the rays from the mirror and the illusion was visible from every seat in the room. The figures were, of course, diminished images of real human beings, and their size was simply due to the image being much closer to the concave mirror than the object was. The axis of the concave mirror was at right angles to the line of vision of the spectators, and the rays were turned towards the latter by a combination of plane mirrors which at the same time inverted the image.

Phantasmagoria.—The ordinary projection lantern or magic lantern was in its early days much used for producing illusions. It is said to have been invented by the monk Roger Bacon in the thirteenth century, but is first clearly described in a book that appeared at Rome in 1645. Already in the eighteenth century they had begun to make mechanical slides with a simple movement such as a smith hammering a horse shoe or a mother spanking her child. These slides were painted by hand; this was long before the era of photography. But it was not until about 1802 that the possibilities of the projection lantern were fully utilised. In that year M. Philipstal gave an exhibition in London and Edinburgh under the name of *Phantasmagoria* which produced a great sensation. To quote the account of it given in Brewster's *Natural Magic*:

"The small theatre of exhibition was lighted only by one hanging lamp, the flame of which was drawn up into an opaque chimney or shade when the performance began. In this "darkness visible" the curtain rose and displayed a cave with skeletons and other terrific figures in relief upon its walls. The flickering light was then drawn up beneath its shroud, and the spectators in total darkness found themselves in the middle of thunder and lightning. A thin transparent screen had, unknown to the spectators, been let down after the



Reproduction of an Engraving of 1797 showing a Phantasmagoria Exhibition.
(From 'La Lumière,' A. Turpain, Ch. Delagrave, Paris.)

PLATE V.

disappearance of the light, and upon it the flashes of lightning and all the subsequent appearances were represented. This screen being half-way between the spectators and the cave which was first shown, and being itself invisible, prevented the observers from having any idea of the real distance of the figures, and gave them the entire character of aërial pictures. The thunder and lightning were followed by the figures of ghosts, skeletons, and known individuals, whose eyes and mouth were made to move by the shifting of combined sliders. After the first figure had been exhibited for a short time, it began to grow less and less, as if removed to a great distance, and at last vanished in a small cloud of light. Out of this same cloud the germ of another figure began to appear, and gradually grew larger and larger, and approached the spectators till it attained its perfect development. In this manner the head of Dr. Franklin was transformed into a skull; figures which retired with the freshness of life came back in the form of skeletons, and the retiring skeletons returned in the drapery of flesh and blood.

"The exhibition of these transmutations was followed by spectres, skeletons, and terrific figures, which, instead of receding and vanishing as before, suddenly advanced upon the spectators, becoming larger as they approached them, and finally vanished by appearing to sink into the ground. The effect of this part of the exhibition was naturally the most impressive. The spectators were not only surprised but agitated, and many of them were of opinion that they could have touched the figures."

Plate V is a reproduction of a contemporary engraving depicting such an exhibition. The variation in size of the image was produced by moving the lantern and at the same time changing the focus. The vapour ascending from the vessel in the engraving acts as a screen for projecting the pictures on.

We all know the story of the small boy who when asked to pay a penny for admission to a magic lantern entertainment given by some religious organisation, exclaimed "What! pay a penny for standing pictures?" and the modern reader

wonders how the exhibition described above had such a vogue in its day, especially as the source of light used in the lanterns was miserably weak in comparison with our arc lamps. So poor were the artificial sources of light then, that summer was regarded as *the* season of the year for performing experiments in optics; then the sun was available. But people were less sophisticated in these days, and knowledge of the laws of optics was not so widely diffused. When the kaleidoscope, a scientific toy which no self-respecting boy would look at nowadays, was put on the market in 1815, three hundred thousand were sold in six months.

CHAPTER VIII

THE LIGHT OF THE FUTURE

The Optical Trade.—Everyone who has read the newspapers for the past few years must have learned about the importance of the optical glass industry, how although the initial cost in money of the optical glass used in this country is small, still when worked up in the form of lenses and prisms for use in scientific instruments it gives employment to highly skilled workers, and these instruments in time of war might be vital to the nation's existence. Hence it is necessary that we should not be dependent upon a foreign country for the supply of that optical glass. The Prussian government subsidised the Jena glass factory, etc., etc.—we all know the rest of the argument ; the optical glass industry is the stock illustration of the leader writer on key industries, and the nature of the reference to it depends on the political associations of the newspaper.

What has been said above about the optical glass industry is true, though Messrs. Zeiss have made a statement* which must be accepted as authoritative, that the only state subsidy ever paid to the Jena glass factory was one of £3,000 in 1883 ; Messrs. Zeiss at the same time hint, that Faraday had previously obtained a larger subsidy from the English government for his experiments on glass melting. The manufacture of optical glass at Jena was financially successful from the first. But there are many erroneous ideas prevalent about the optical instrument industry. The good German instruments were never cheap before the war. The Germans had a rhyme, " Zeiss ist Zeiss, Aber Zeiss fur Preiss " (Zeiss is Zeiss, But Zeiss for price), which hits the matter off very neatly, and the

* *Nature*, October 20, 1921.

German industry was not more efficient than our own. It was aided, no doubt, by the protectionist policy of the country, but I think much more by the co-operation of the different firms. They did not compete needlessly with one another for the home market.

Their advertisement was also more effective. This happened by accident more than anything else. We are all familiar since the war with the psychology of propaganda. The German industry certainly made an appeal to the English man of science. He read about the endeavours of Carl Zeiss to apply scientific principles to the construction of his instruments, of his co-operation with Professor Abbe, of the production of new glasses, of the great development of the Jena industry, and the distribution of profits that went back to the university under the scheme of the Carl Zeiss Stiftung, something like £100,000, I believe, and did not perceive how subtly he was being influenced. The story of the "village industry" or the "early struggles of the founder of the firm" as applied, say, to the selling of soap, would have been much too crude for the men who ordered the microscopes. But the story of Zeiss and Abbe got in under their guard in the most delightful manner. Added to which the microscopes undeniably were good.

This is, however, a digression. The object of introducing the optical trade into this chapter was to state that it has received much too large a share of public attention, and too large a proportion of workers are directing their attention towards its scientific side. The men in the industry fail to make fortunes not because they lack science, but because an instrument lasts such an extremely long time once it is made. The optical trade by no means offers financially or economically the most important application of the science of light. It stands a long way behind illuminating engineering, the profession which deals with the invention and provision of artificial illumination. The average householder spends far more money on artificial light than he does on telescopes. This is an important truth which the newspapers do not properly appreciate.

The Wasted Energy.—Most houses which have electric light are equipped with tungsten filament lamps. These lamps give about one candle power for each 1¼ watts power consumed. But only 3½ per cent. of the energy consumed is utilised as light.

Most of our energy comes from coal. In the case of a locomotive pulling a train coal is burned in its furnace, steam produced, and work done in hauling the train. It is found that only 8 per cent. of the energy in the coal is employed usefully in hauling the train. The remainder is lost as heat into the atmosphere. The efficiency of the locomotive as a transformer of energy is thus only 8 per cent. But the efficiency of the glow lamp as a means of transforming electrical energy into light is still less than this ; 96½ per cent. of the energy is lost as heat. This is not the fault of the Electricity Supply Department. It is in the nature of things, as they are at present. We can no more get light without heat than we can get an orange without a skin. Consequently the householder who is paying a bill of, say, £3, for electricity these hard times used only 2s. worth of light, but had to buy £2 18s. worth of dark heat along with it ; this is no doubt an inspiring thought for him.

And the tungsten filament lamp is very efficient as artificial illuminants go, about three times as efficient as the old carbon lamp which preceded it. Most of us remember an advertisement depicting the advantages of one of the new tungsten lamps. It represented a gentleman contemplating a piece of paper, presumably a bill for electrical energy, with a pleased expression irradiating his countenance, and the legend below, " 70 per cent. of my bill saved." It is really true that the new lamps saved under certain circumstances about two-thirds of the bill. But not always. They were at first only supplied in large sizes, about 32 candle power, so if a single 16 candle power carbon lamp was replaced by a 32 candle power lamp of the new kind, only one-third of the energy was saved. The tendency was rather to give the consumer—within limits—three times as much light for the same money than the same light for one-third of the money. This is what

the trade journals euphemistically referred to as educating the public up to a higher standard of lighting. It would, of course, have been a bad thing for the electricity supply undertakings, if the consumption of electrical energy suddenly fell everywhere to one-third of its value.

The Energy Spectrum.—If the end of a poker is heated in the fire, it first remains black; then, as its temperature rises, it begins to glow with a dull red heat, next with an orange red, and finally with a white heat. It is the same with other solid bodies; if a carbon glow lamp is turned off, the filament remains in a "red-hot hairpin" stage for an instant or two

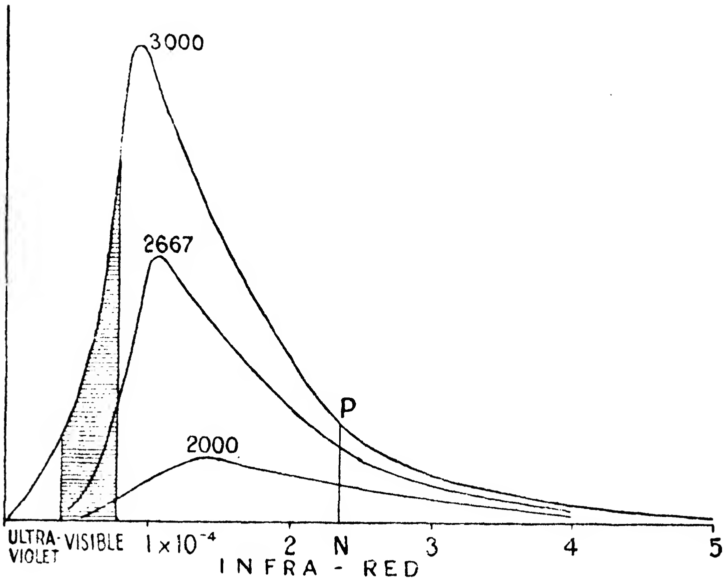


Fig. 62.

before it goes out. Now in the study of the efficiency of artificial illuminants, much help has come from a consideration of the behaviour of what is known as the "theoretical black body." We shall omit the exact definition of this body, and merely state that carbon, the carbon filament of the glow lamp or the carbon of the electric arc, is close enough to the definition for practical purposes.

Fig. 62 represents the distribution of the energy in the spectrum of a piece of glowing carbon at three different temperatures, 2000°K, 2667°K and 3000°K. The first of these temperatures is about the temperature of the filament in the carbon glow lamp, the last is considerably below the temperature of the crater of the arc. Reckoned into degrees Fahrenheit, the scale used in this country in daily life, they are respectively 3141°, 4341° and 4941°. The horizontal scale gives wave-lengths in 10^{-4} cm., so much the greater part of the scale represents infra-red. The area above the visible spectrum is shaded horizontally.

If we take any point N, and draw an ordinate NP from that point up to cut a curve at P, the height of PN represents the amount of energy radiated at that part in the spectrum. Now if the point P starts at the extreme infra-red end, and moves along the highest of the three curves, PN gradually increases until a point in the near infra-red, about $\lambda = 9700$ A.U., or $\cdot 97 \times 10^{-4}$ cm., is reached. Here the radiation is a maximum. It then diminishes rapidly through the visible spectrum, being much less at the violet than at the red end. This is in agreement with Herschel's experiment described on p. 36. If we consider the highest curve, the whole area between the curve and the horizontal scale represents all the energy radiated, while the shaded part represents the energy radiated as light; the latter is only a small fraction of the whole area.

It will be observed from the figure that when the temperature is increased, the wave-length of maximum radiation moves towards the visible spectrum, and the shaded fraction of the area increases. Increasing the temperature increases the fraction of energy radiated as light. If the temperature is too low, as in the case of the poker at black heat, all the energy is radiated as dark heat.

The distribution of energy in the spectrum of the sun is given by a curve of the same nature as those in the figure. It corresponds to a temperature of about 6,000°K or 10,300° Fahr. and has its wave-length of maximum emission in the green of the visible spectrum, close to the wave-length to which the eye is most sensitive at low intensities of light. This

has not happened by chance, but is the result of long ages of evolution on the part of the eye.

We must keep Fig. 62 in mind when considering the progress of artificial illumination. All improvements have consisted in increasing the shaded part of the area. The various workers who have striven to improve the illuminants may not have regarded their work under this aspect; they may have been directed solely by empirical considerations. But the modern theoretical standpoint enables us to understand the drift of their work in many cases better than they did themselves.

Flames.—Flames are the simplest and historically the first means of artificial illumination. According to the Greek myth Prometheus first discovered the use of fire, or stole the celestial fire according to another account, and was punished by Zeus for his misdeed by being chained to a rock where an eagle perpetually gnawed his liver. The myths are supposed to be a survival from the animistic stage in human development when man could not think except in terms of personality, when he regarded the trees, rivers, clouds, etc., as living beings; then, for example, when the river rose in flood, he thought it was a god who was angry with him. It is difficult to know what started the legend of Prometheus, but the eagle perpetually gnawing at the liver may typify the agony of discovery, the perpetual worrying and brooding of the mind over the problem. Or the whole legend may simply testify to the unhappy fate which the world commonly reserves for its great discoverers, those so completely under the sway of a great idea, that they cannot stoop to the precautions of the market place.

In any case, fire was probably at first obtained accidentally as a spark from a flint, and this accidental discovery led to the pine torch, the oil lamp of ancient Rome, the rushlight of the Middle Ages, the burning whale, seal or bear fat of the Esquimaux, the tallow dip and the paraffin candle, coal gas and acetylene gas. In all these cases the fundamental process is substantially the same; the light is given out by red-hot

particles of carbon or soot inside the flame, and the distribution of energy over the spectrum is very similar to the lowest curve on Fig. 62. All flames are extremely inefficient as energy transformers. One case, the Hefner lamp, which has been studied in great detail, and which is very similar to the ordinary candle flame, may be taken as typical of the rest. 90½ per cent. of the energy of combustion in this lamp is carried away in convection currents as heat by the products of combustion or lost by conduction to the lamp itself; only 9½ per cent. is radiated. And of the fraction radiated, only 1 per cent. is light; the rest is dark heat. Thus only 1 per cent. of 9½ per cent.—*i.e.*, about one-tenth of 1 per cent. of the energy consumed—is transformed into light; the remainder is wasted in the process.

Electric Glow Lamp.—When an excessive current passes along a wire, it becomes red hot and burns up. If, however, it is maintained in a vacuum, so that there is no oxygen available for it to combine with, it remains red hot for as long as the current flows. This is the principle of the electric glow lamp, with the appearance of which we are all so familiar. It can easily be shown, that the space inside the lamp is a vacuum, for if a lamp that is spent is crushed under the heel of one's boot, it bursts with a bang like an inflated paper bag.

One of the first materials employed for the wire of the glow lamp was platinum. Edison devoted a considerable amount of attention to a platinum glow lamp. But it was never a commercial success, because the temperature of platinum has to be raised very nearly to its melting point in order to produce light economically, and if the voltage of the electricity supply increased slightly above its normal value, as it occasionally does, the filament melted through. So carbon was tried, and proved successful.

The carbon glow lamp is associated principally with the names of Edison and Joseph Wilson Swan. It was first placed on the market about forty years ago, and held the field for about thirty years, being displaced by the wire filament lamp. The first of the wire filament lamps, the osmium lamp,

invented by Auer von Welsbach appeared in 1902, and the tantalum lamp appeared three years later. But these were only qualified successes. The tungsten lamps, the first of which was the Osram, and which figure under many other trade names, appeared shortly afterwards. At first the filament was prepared from a paste consisting of the metal in a finely divided condition together with some binding or stiffening agent. This paste had the consistency of putty, and was squirted through a very fine hole in a diamond under a pressure of several tons per square inch. The filaments thus formed were heated in air, when they became more coherent. They were then sintered—*i.e.*, heated nearly to their melting point, by the passage of an electric current, the sintering being carried out in gases which attacked the binding agent, so that finally a filament of pure metallic tungsten remained. As prepared in this way the filaments were not very strong ; they are now wire drawn and consequently much stronger.

The efficiency of the wire filament lamp is greater than that of the carbon filament lamp because its temperature is higher—*i.e.*, the maximum of the curve (*cf.* Fig. 62) is slightly nearer the visible spectrum, and consequently a greater proportion of the area comes above the visible spectrum, also because the shape of the curve is slightly different, the ordinates in the far infra-red being not so high.

Watts per Candle.—The practical man is accustomed to measure the efficiency of an electric lamp, not by the percentage of energy it transforms into light, but by the number of watts it requires to give one candle.

A practical illustration will make the phrase clear. The room in which this is written is illuminated by a wire filament lamp of 32 candle power. That is, it gives as much light as 32 standard candles would, if when placed close together they did not get in the way of one another's rays. The standard candle is the legal unit of light. If the bulb is examined the figures 250-40W are found to be sandblasted on it. This means it takes 250 volts and 40 watts. The watt is the unit

of electric power. So the lamp requires 40 divided by 32, or $1\frac{1}{4}$ watts per candle. Now the price of the electrical energy supplied is $5\frac{1}{2}$d. per Board of Trade unit, and the Board of Trade unit or kilowatt-hour is equal to 1,000 watts for an hour. The lamp consequently costs

$$\frac{40}{1000} \times 5\tfrac{1}{2}\text{d. or } \frac{22}{100} \text{ of a penny}$$

to run for one hour. Each candlepower of light supplied thus costs $\frac{22}{32 \times 100}$ or $\frac{11}{1600}$ of a penny per hour.

The old carbon glow lamp required $3\frac{1}{2}$ watts per candle, so each candle power of light it could supply cost $3\frac{1}{2}/1\frac{1}{4}$ or $\frac{14}{5}$ times as much.

The Incandescent Mantle.—The incandescent gas mantle was invented by Karl Auer, Freiherr von Welsbach, in 1885. The principle of the Welsbach mantle—the German name for them is "Auer stockings"—is, that a fabric of organic material, Ramie silk, for example, is impregnated with a mixture of two rare earths, thorium oxide and cerium oxide, in the proportion of about one part of the latter to 99 parts of the former; the organic material is then burnt off, the oxides remain, and are heated in the colourless Bunsen flame until they radiate light. The invention was not made accidentally. Auer von Welsbach had been a pupil of the celebrated chemist Bunsen at Heidelberg, and had made a special study of the rare earths; he experimented systematically with different earths and different mixtures, until he got the formula which gave the strongest light.

The energy spectrum of the incandescent mantle is of an irregular form, quite unlike the curves shown in Fig. 62.

The Arc Lamp.—The electric arc is formed by connecting two rods of carbon to a battery of cells, so that their difference of potential is about 80 volts, pushing the ends of these rods together—striking the arc, as it is called—and then pulling them apart, when a bright discharge characterised by intense light and heat passes from the one carbon to the other. As the current passes, the extremities of the carbons, although similar to begin with, soon begin to show differences. The end of the negative carbon becomes pointed, while the end

of the positive one becomes hollowed out into a crater. Much the greater proportion of the light of the arc comes from this crater. As the current passes the carbons are consumed, the positive twice as fast as the negative one.

The arc lamp has been known for about a century. It is only convenient to use it in large units, 500 candlepower or more, and so it has been employed mostly for the lighting of streets and large halls. It is then furnished with an automatic arrangement for striking and maintaining the carbons at a suitable distance from one another ; this arrangement often does not work well, and as a consequence the street arc lamps are often seen jerking and spluttering.

Originally the arc required about 1·4 watts per candle. Some years ago, however, a new type of arc, the " flame arc," was introduced in which the original solid carbon rod was replaced by one with a core, the latter consisting of carbon, potassium silicate, and either calcium, cerium, or strontium fluoride. When the current passes, the fluoride volatilises and an intense coloured flame appears between the carbons, golden yellow, white, or red respectively, according to which of the afore-mentioned three fluorides is used. The presence of this flame greatly increases the efficiency of the lamp ; the yellow flame arc requires only ·4 watt per candle.

The Half Watt Lamp.—The most successful innovation of recent years has been the introduction of the " half watt lamp " which was invented by Dr. Irving S. Langmuir in the laboratory of the General Electric Co. at Schenectady, Mass., U.S.A. It consists of a filament in a glass bulb filled with an inert gas such as argon or nitrogen. As a result of the presence of the gas the filament stands a higher temperature without disintegrating than it otherwise would, and, as the name implies, the lamp requires only one half watt per candle. The war interfered with the introduction of this lamp into Great Britain, and at first it had to be imported from Holland. Hitherto it has been available only in large units, 200 or 100 candle power, so has not come much into domestic use. But there is no doubt it has a great future.

Gas versus Electricity.—Progress in lighting has in recent years been somewhat in the nature of a duel between gas and electricity. The old gas jet was in possession when the carbon lamp appeared. The latter began to displace it, when the situation was changed by the invention of the Welsbach mantle. The Welsbach mantle was followed after a time by an electric imitation, the Nernst filament, in which the passage of a current caused a filament of rare earths to radiate in pretty much the same way as the Welsbach mantle radiates. This lamp was, however, only a qualified success. The gas industry met the development of the electric arc by the introduction of high pressure incandescent lighting ; in this system the mantle, which is a very large one, is heated to a higher temperature than in ordinary domestic use, and is thus rendered more efficient. The war and consequent disorganisation it produced have naturally retarded progress. But it is certain that the last word has not been said by either of the two great industries involved.

The Light of the Future.—Within the past twenty years or so we have seen the efficiency of the electric glow lamp change from the $3\frac{1}{2}$ watts per candle of the carbon lamp through the 2·2 of the Nernst, the 1·9 of the tantalum, the 1·2 of the tungsten to the 0·5 of the gas-filled half watt lamp. How far is the progress to continue ? I do not know of any exact determination of the efficiency of the half watt lamp as an energy transformer, but should imagine it must be about 9 per cent. There is consequently other 91 per cent. to work on ; what are the chances that we shall be able to draw upon it ?

We may first of all approach the problem from the standpoint of the energy curves shown in Fig. 62. If the temperature is increased, the maximum of the curve moves into the visible spectrum ; if it is increased still further, it moves into the ultra-violet. Obviously there is one temperature for which the shaded fraction of the area is a maximum. As a result of calculation I have obtained the following figures :

TEMPERATURE IN DEGREES KELVIN.	PERCENTAGE OF ENERGY RADIATED AS LIGHT.
1000°	0·0
1500°	0·0
2000°	1·7
3000°	14·6
4000°	31·8
6000°	49·7
8000°	47·7
12000°	18·6

The most favourable temperature is not far from the temperature of the sun. This is because, as has been stated on p. 122, our eyes have adapted themselves to the sun through long ages of evolution. The efficiency of the sun as a source of light is round about 50 per cent.

But it would be impossible to get any temperature approaching the sun in a lamp. Carbon has the highest melting point of all the elements, namely, about 4000°K, and in the glow lamp it has to be operated at temperatures very much below this. So the practical difficulties in the way of heating solid bodies either by flames or electric currents to much higher temperatures than we have already attained show, that no very great progress will be made on this line. Some progress will undoubtedly be made, but not of a sensational nature.

There is, however, another line of advance of a more promising nature. It may be possible to obtain light without heat at all. Let us for a moment forsake the sober realm of fact and turn to fiction. In the *First Men on the Moon* H. G. Wells states, that the inhabitants of the moon illuminated their caverns by a liquid which was made by machinery and dripped luminously into a tank of light. It was a cold blue light, a sort of phosphorescent glow, but infinitely brighter, and from the tanks into which it fell it ran in conduits athwart the cavern. When it splashed on the feet of the two earthmen, it felt quite cold, and made their feet luminous for a long time afterwards. Now while H. G. Wells has a vivid and active imagination, it is by no means an unfettered one.

He may generalise inaccurately from his data, but he never generalises without data. Is there anything to justify the belief that we shall one day turn on light at a tap and carry it about in pails, in the same way as we now carry about water?

When a gas is enclosed in a glass tube at a pressure of two millimetres of mercury or so, and an electric discharge from the secondary of an induction coil is passed through the tube by means of platinum electrodes sealed through its ends, the gas in the tube becomes luminous. Such tubes are called Geissler tubes or vacuum tubes, and they form a frequent exhibit at popular science lectures. Now the temperature inside certain vacuum tubes has been measured and has been found quite low, about 100° Fahr. or so. And in the case of a nitrogen tube investigated by K. Angström 90 per cent. of the energy radiated was light. But there was a large convection loss from the tube, so that on the whole only 8 per cent. of the energy consumed was converted into light. These figures are, however, sufficiently different from those given by glow lamps to show that we are here dealing with an entirely different process, and indeed in the case of the vacuum tube it is generally assumed that the energy of the electrons, of the electric current, passes directly into light without going through heat as an intermediate stage. The term luminescence has been coined to denote this process.

Vacuum tubes of immense size, 40 to 220 feet in length and about 2 inches in diameter, have been used to a small extent commercially as a means of artificial illumination. They were worked out and put on the market by Mr. D. McFarlan Moore who had in 1907 been experimenting on them for twelve years. One which was installed at the Savoy in London was found by Professor J. A. Fleming to require 1·78 watts per candle.

These tubes are a case of luminescence. The possibilities of this means of producing light are by no means fully explored yet. It does not seem probable that a liquid will ever act as an independent light source for a great length of time, as described in the novel just quoted, but it is undoubtedly possible that a gas or solid may luminesce with extreme

efficiency under exceptional conditions, when stimulated by an electric current or otherwise. The interaction of radiation, both light rays and streams of electrons, with matter is by no means understood yet, and there is no saying what it may lead to. If we obtain any striking application of luminescence to artificial illumination, it will probably not come from the laboratory of an electrical trade association or as the result of a direct search for it, but as the result of some investigation undertaken with a different object altogether. Or, in other words, it is much more likely to come from the pure than the applied scientist.

In view of the interest and importance of the subject, even taking it at its lowest level, namely, that when the householder wishes 2/- worth of electric light he has to take £2 18s. worth of useless dark heat along with it, everyone will admit that the discovery of the perfect light, the light that is all light and is unaccompanied by useless dark heat, is one of the most pressing problems of applied science. In this field we require research and more research and more research still.

The Light of the Firefly.—There is all the more hope for success in the quest of the perfect light, because according to some authorities Nature has already produced it. Certain insects emit light at night. What is the nature of this light? Is it accompanied by ultra-violet or infra-red rays? A celebrated investigation by Langley and Very was published on this interesting subject in 1890. They caught specimens of the Cuban firefly, *Pyrophorus Noctilucus*, examined its light, and found that the energy radiated lay all in the middle of the visible spectrum. They also found that, apart from the heat due to bodily processes, there was no radiation in the infra-red. Langley concluded that the firefly's radiation was consequently all light, and that the firefly was the most efficient source of light known. He drew the conclusion that, what Nature could do on this small scale, man must be eventually capable of doing on a larger scale.

Since Langley's time another firefly, the *Photinus Pyralis*, has been investigated, and its light has also been found to be confined to the middle of the spectrum. It has, however,

not been investigated in the infra-red, and owing to the very small quantities of heat involved doubts have been expressed as to the accuracy of Langley's statements about the infra-red radiation.

On Saving Light.—It is not generally realised how much light is wasted in the decoration and adornment of an ordinary living room. The muslin screens and lace and other curtains so dear to the feminine mind are probably responsible for keeping out half the light which would otherwise enter at the window. The ceiling of a room is usually white, and no fault can be found with this from the point of view of saving light; when clean it probably reflects 80 per cent. of the incident light. But the wall paper often darkens the room unnecessarily; as a result of measurement a yellow wallpaper was found to reflect 40 per cent. of the light, but an emerald green only 18 per cent. Some globes and electroliers, particularly the more expensive ones, are very wasteful of light; a globe or shade should prevent the eyes from being dazzled by direct rays from the light, but beyond this they should absorb as little light as possible.

Of course economy in lighting is only one of the factors to be considered in fitting or decorating a room. But it is one to which very little attention is paid.

A Caution.—Some of the readers of this chapter may have their interest in the subject awakened, and go to public libraries or encyclopedias for further information. In which case they should not look up the word "Illumination"; they will find the information under this head has nothing to do with lamps, but is concerned only with the colouring of initial letters in medieval manuscripts, a subject on which much has been written. Indeed most public libraries are very scantily furnished with modern books in applied science. The largest one to which I have access has, or had until recently, no entry in the catalogue under "cinematograph," but under "bioscope" appeared "Bioscope, The, explained" by G. Penn. When the unhappy reader received this volume across the counter, he found the full title to be "The Bioscope or Dial of Life explained, to which is added a Translation of

St. Paulinus's Epistle to Celantia, on the Rule of Christian Life: and an elementary view of General Chronology." This is doubtless a work of some value in its class, as it is a second edition; but it is of no use to the schoolboy who wishes to make a model cinematograph. And in the magazine department of the same library there appears a magazine called *Light*, which has nothing whatever to do with light, but deals with spirit communications and poltergeists, and claims to be "The Little Paper with a Great Message."

CHAPTER IX

PHOTOCHEMISTRY AND ALLIED EFFECTS

A Pendulum Experiment.—We shall begin this chapter by describing a simple experiment with a pendulum, which supplies to a certain extent the key to the matter contained in the chapter. Some of our readers have no doubt been reading the books on auto-suggestion which have become so popular recently, and may have become suspicious of pendulum experiments owing to their non-success with the pendulum described as a first lesson in auto-suggestion. But there is one great difference between the experiment to be described now, and those in the books on auto-suggestion ; this experiment works.

Take a small lead sphere about half an inch in diameter and hang it up by a thread about a yard long. Any lump of metal or even a heavy button will do almost as well as the sphere. Wait until it comes to rest vertically under the point of suspension. Then take a piece of note paper folded into a strip 6 inches the one way and 1 inch the other ; hold this paper by the one end, and try to deflect the bob of the pendulum by bringing the side of the strip against it and pushing steadily. Owing to the bending of the paper the utmost deflection that can be obtained is probably about a quarter of an inch. If, however, the pendulum is tapped repeatedly in one direction with the strip of paper, the taps being delivered when the bob is at the middle of its swing going in that direction, then the oscillations may become quite large, 3 or 4 inches on each side of the vertical.

The force applied is no greater than before. The paper still bends. But the experiment shows that by timing a weak force, so as to make it synchronise with the natural period of

a system, quite large results may be obtained. If the taps are not quite in time with the swings, oscillations are produced, but these oscillations are not so large as when the synchronisation is perfect.

Now as has already been mentioned in Chapter IV, atoms contain electrons. These electrons have a natural period of vibration the same as a pendulum. When a light wave passes through a material, every time a crest passes, the electrons receive an impulse in one direction, every time a trough passes they receive an impulse in the opposite direction. If the period of the wave coincides with the period of the electrons, the latter oscillate vigorously and acquire energy. The wave at the same time loses energy, and may be quite extinguished. Consequently, if the spectrum of the light is examined after it passes through the substance, the light of this wave-length is lacking. This is, for example, how we explain the absorption bands in the spectrum of cobalt glass which is reproduced in the second coloured plate.

What happens to the energy that the light wave loses? It may be converted into heat without any alteration in the structure of the medium. This was formerly thought to happen in the great majority of cases, and a mathematical theory of the process has been worked out on this basis which in certain fields has been very successful. On the other hand, the absorbed energy may be re-emitted as light of a different wave-length; this is the phenomenon known as fluorescence. Or it may cause the ejection of electrons from the atoms. These latter alternatives happen when X-rays are absorbed, and owing to the identity of X-rays with visible light it is possible that they occur to a greater extent in the visible spectrum than has hitherto been supposed, but are masked by other phenomena. In any case the matter is not fully understood. But there is no doubt whatever that selective absorption—*i.e.*, the cumulative effect of suitably timed small forces such as are exerted by light waves—is of very great importance in many different fields of work; we shall illustrate this by a number of different examples.

The Photographic Process.—When light falls upon gelatino-

chloride printing paper, it decomposes the silver chloride. There are different opinions as to how exactly the silver and chlorine atoms are held together in silver chloride, but there is general agreement that one electron, sometimes referred to as the valency electron, plays a large rôle in the matter. Silver is electropositive and chlorine electronegative; in the electrolytic cell the silver atom acquires a positive charge and the chlorine atom a negative charge. We are therefore to imagine that an electron represented by the black disc in Fig. 63 gets detached from the silver atom and attached to the chlorine atom; the system chlorine atom + electron has then one negative charge, the silver atom has one positive charge, and the two are consequently held together by electrostatic attraction.

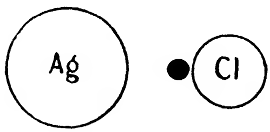


Fig. 63.

When the light wave falls upon the silver chloride molecule, in certain circumstances the latter is decomposed, metallic silver being separated out. Doubtless the most popular way to exhibit the theory of the process would be by animated drawings on the cinematograph screen, but for present purposes Figs. 64, 65, 66 and 67, must be accepted as substitutes. Fig. 64 shows the light wave approaching the molecule; Fig. 65 shows the wave after it has passed the molecule. The amplitude of the wave is slightly less; it has lost some of its energy. The


Fig. 64.

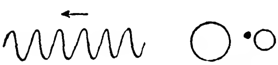


Fig. 65.

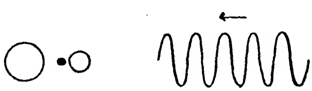


Fig. 66.

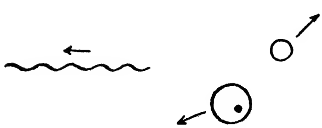


Fig. 67.

electron is vibrating about its mean position ; it has acquired the energy that the wave lost. But these vibrations will die down presently, and the molecule will be, as if the wave had never passed.

Fig. 66, however, represents the approach of another wave of different period and wave-length. This time the period of the wave and the natural period of the oscillations of the electron coincide. Each crest comes exactly at the most favourable time for increasing the effect of the crests that have gone before. Consequently the vibrations of the electron become larger and larger until it is finally shaken out of its position as a link between the two atoms, and falls back into the silver atom. The two atoms are then neutral and fall apart. Fig. 67 shows the last stage. The wave has now passed completely, and it will be observed, has lost nearly all its energy.

The point to note is that each electron which acts as a link between two atoms has a natural period of vibration. The system is perfectly stable against all disturbances from without except a series of impulses timed to coincide with this period. The magnitude of the impulses does not matter so much as their timing, and, of course, it is impossible to get the impulses timed more accurately than in a light wave. It is this that renders the light wave such an effective means of decomposition.

The photographer who has studied Figs. 64 to 67 will naturally ask if these Figs. represent what occurs in P.O.P.—printing out paper—where the paper actually changes colour under the action of the light wave, what happens in the dry plate where the change is not visible until the plate is developed. Different answers can be given to this question, none of which is very satisfactory, and their discussion would lead too far. While Figs. 64 to 67 undoubtedly indicate the main idea in the process, the rest of the matter is by no means settled yet.

The Selenium Cell.—In Chapter III it was explained how, when light fell upon a thin strip of the metal selenium mounted in an arrangement called a selenium cell, the electrical resist-

ance of the latter altered. The uses of the selenium cell in the optical telephone and optophone were described in that chapter. The result of varying the wave-length of the incident light has been investigated. There is always one wave-length for which the change of resistance is a maximum, and the effect falls away on both sides of this maximum, but there is no characteristic wave-length sensibility curve for light-sensitive selenium, except when that selenium is made light sensitive under very definite physical conditions. The selenium in the various commercial cells is apparently made up of varying crystal structures; only when this variation in structure is eliminated are consistent results obtained. Then each crystalline form has a characteristic curve of its own.

Fig. 68 shows results obtained by L. P. Sieg and F. C. Brown* for an acicular, hexagonal crystal. The horizontal scale gives wave-lengths measured in 10^{-4} cm., so it starts at the violet end of the spectrum and goes a little way into the infra-red. The vertical scale represents the change of the electrical resistance produced by the illumination. The intensity of illumination as measured by a thermopile was the same throughout the spectrum. The conductivity of the crystal varied considerably with the pressure on it, so readings were taken both for a high and low pressure, also for a low intensity of the incident light.

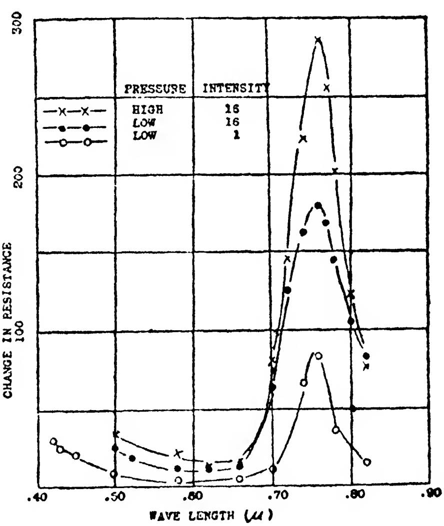


Fig. 68.

* *Physical Review* (2) 4, p. 511, 1914.

It will be observed that the three curves have all a maximum at about $\cdot 76\mu$—*i.e.*, the end of the visible spectrum. Clearly, we are here dealing with selective absorption. An electron is set into vibration by the light wave; the oscillation becomes so large that it escapes from its atom. Thus the number of free or conductivity electrons is increased, and the resistance of the cell diminished. Here it is not a case, as in silver chloride, of an electron falling out of one atom into another; it escapes from the atom and becomes free.

Bleaching of Visual Purple.—Visual purple or rhodopsin is a substance discovered in the retina of frogs' eyes in 1851, and since then shown to exist in the human eye, and the eyes of monkeys, oxen, crocodiles, pigeons, etc. As its name implies, it is of a purple colour, and consequently absorbs the middle of the spectrum. It bleaches on exposure to light. In virtue of this property it can be used for forming optograms or images of luminous objects. These can be fixed with an alum solution in somewhat the same manner as a photographic print is fixed. Two to seven minutes' exposure to light is sufficient to give an optogram on the frog's retina.

Visual purple is evidently of the greatest importance for the process of vision. It is generally admitted that vision at low intensities is due in the first instance to the rays of light bleaching and decomposing the purple; the products of decomposition then set up impulses which travel along the fibres of the optic nerve to the brain. According to Dr. Edridge-Green this is the mechanism of the process of vision at all intensities. Visual purple is regenerated in the living retina after bleaching. The phenomena of dark adaptation in the human eye lead us to suppose that the recovery follows the course of a bi-molecular reaction.

Fig. 69 gives some extremely interesting results obtained by Trendelenburg.* The abscissae give wave-lengths, this time measured in $\mu\mu$,—*i.e.*, they require to be multiplied by 10 to bring them into A.U. The ordinates of the points indicated by · · · give the bleaching values of the light of each wave-length for rabbits' visual purple, on an arbitrary

* *Ztsch.. f. Psychol. u. Physiol. d. Sinnesorg.* 37, 1, 1904.

scale. The bleaching values are the reciprocals of the times taken by the different wave-lengths to destroy the same proportion of the visual purple. The ordinates of the points indicated by × × × give the human luminosity curve at low intensities—*i.e.* the relative brightness of the different wave-lengths in the spectrum when the spectrum is one of low intensity. The maxima of both curves occur in the green. It will be noticed that the curves are in good agreement.

It is natural to suppose that here again we are dealing with selective absorption, that in the first instance an electron is

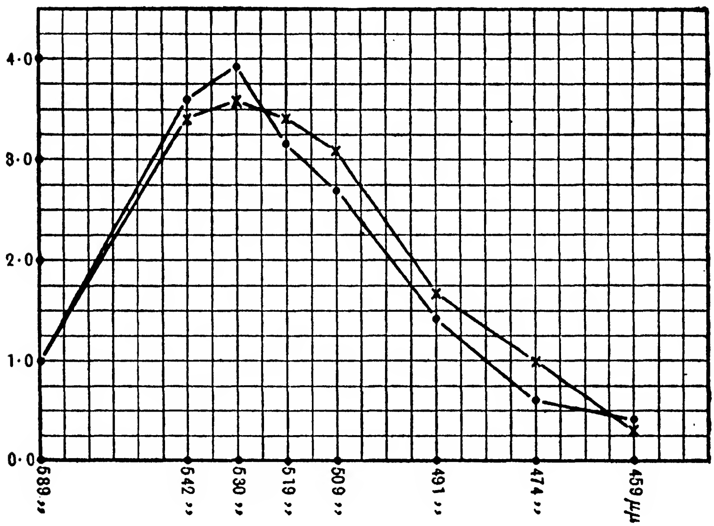


Fig. 69.

From Parson's Colour Vision (Cambridge University Press)

displaced from its position in the atom by the light wave, and a molecule decomposes, that the products of decomposition stimulate the ends of the fibres of the optic nerve, and that when the light stimulus is removed, the products of decomposition recombine into visual purple.

Spectral Sensibility Curve of Volvox Globator.—*Volvox globator* is an elementary form of life found in river water, consisting of little brown things about 1 millimetre in diameter,

each forming a colony of thousands of cells. When light falls on them, the colonies move automatically towards the source. An interesting study of the effect of varying the wave-lengths of the light has been made by Laurens and Hooker.* The colonies were placed in a small glass aquarium on the stage of a microscope. The apparatus was kept in darkness, and the spectrum light allowed to impinge on one wall for a measured time. If no reaction followed, the organism

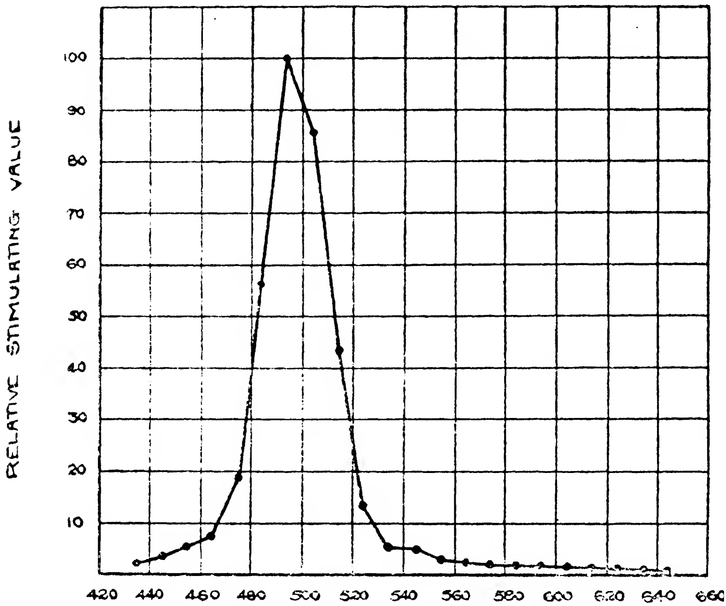
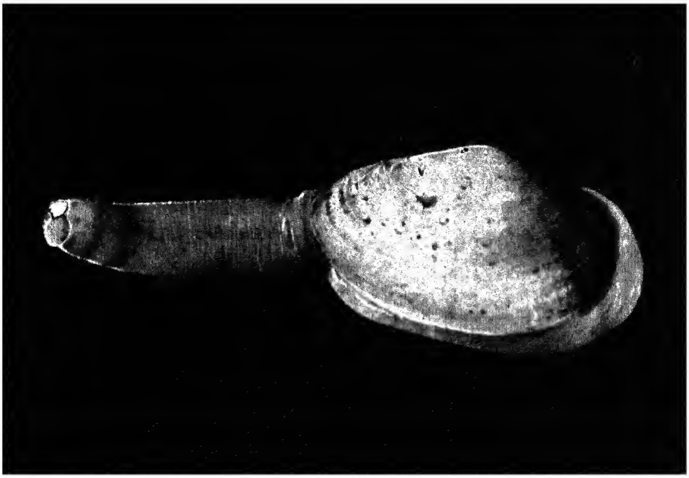


Fig. 70.
(*From The Journal of Experimental Zoology.*)

was given the same exposure again and usually a third time for purposes of verification. Then the duration of the exposure was increased until a reaction—movement towards the source of light—was obtained. Ten colonies were used for each light, each colony exposed several times, and the results averaged. They are shown in Fig. 70. The

[1] *Journal of Experimental Biology*, 30, p. 345, 1920.



S. Hecht in the 'Journal of General Physiology.'

The Clam, *Mya Arenaria.*
Reproduction a little less than life size.

Photograph supplied by Dr. A. Rollier, Leysin, Switzerland.

The School in the Sun—Winter.

PLATE VI.

ordinates are the reciprocals of the exposures just necessary to produce a reaction, and may be regarded as measuring the relative stimulating values of the different wave-lengths, since the light had always equal energy content. The shape of the curve makes it certain that here again we are dealing with selective absorption, that in the first instance the light waves are absorbed by an electron vibrating in a definite period.

Photosensory Process of the Clam Mya Arenaria.—Some very interesting experiments have been made by S. Hecht * on the clam *Mya Arenaria*. An idea of the appearance of this animal may be obtained from Plate VI., where there is a photograph of a living medium-sized individual expanded in sea water. The reproduction is a little less than life-size. When the animal is exposed to light, it always retracts its siphon. The response is quite involuntary on the part of the animal, is well marked, and consists in a movement of the tip of the siphon towards the shell. The movement is about 1 cm., often it is more, and it is rarely less than ½ cm. The response does not occur immediately, but about two seconds after the exposure to light is made, and there is never any doubt about the exact moment when it begins. So the reaction time, the interval from the exposure to the commencement of retraction, can be measured with considerable accuracy.

Hecht used light of seven different colours, the colours given respectively by the Wratten series of spectral filters. Several animals which had been kept for some time in the dark, were exposed to the light, and their reaction time measured with a stop watch. Lights of different intensity were used, as the reaction time varies with the intensity as well as with the colour of the stimulus. Fig. 71 gives some results: the ordinates represent the reciprocals of the intensities of the light necessary to produce a reaction in 3 seconds. It will be noticed that 500 $\mu\mu$. is the wave-length to which the animal is most sensitive, and the sensitiveness falls away rapidly to zero on both sides of the maximum.

* *The Journal of General Physiology*, 3, p. 375, 1921.

Bactericidal Action of Ultra-violet Light.—Plate VII., which is reproduced from a paper by C. H. Browning and Sidney Russ,* shows in an extremely interesting manner the action of ultra-violet light in destroying bacteria. It is, of course, known that ultra-violet light sterilises milk; the method used by Browning and Russ shows precisely to what region in the ultra-violet the bactericidal action is due. A gelatine plate was inoculated with micro-organisms—in the case shown in the photograph *Staphylococcus pyogenes aureus*—instead of sensitising it with a silver salt. A spectrum was allowed to fall upon this plate. On some portions of the plate the micro-organisms were killed by the radiation. The plate was then incubated at 37°C for 48 hours. This encourages a copious growth of the organisms not affected by the radiation.

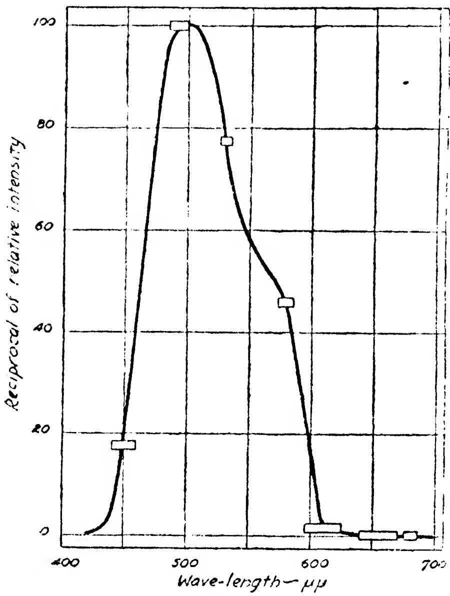
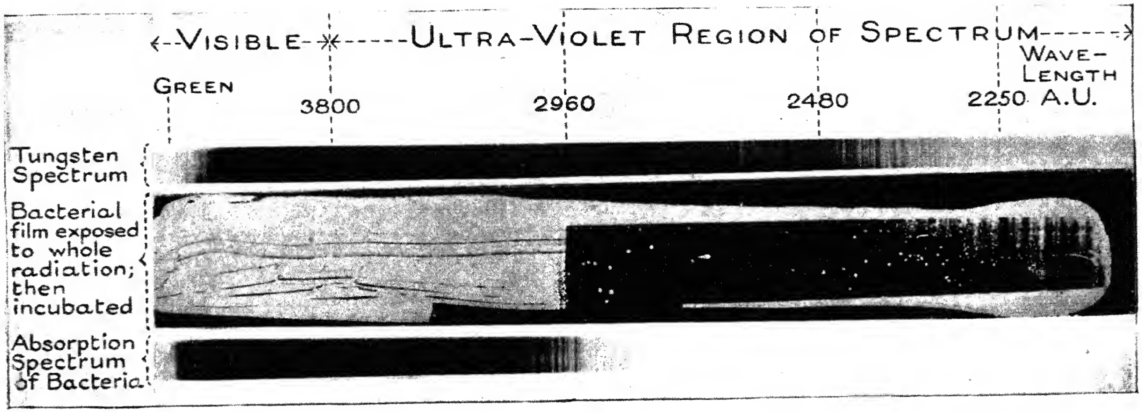


Fig. 71.

The illustration first of all shows the spectrum of the tungsten arc, as photographed on an ordinary dry plate. It will be seen that it extends from the green almost to wave-length 2250 A.U. Then below is shown the bacterial film which was exposed to the same spectrum, accurately in register with the spectrum above. The black portion, to the right of wave-length 2960 A.U. is transparent; all the organisms have been killed here. But the part to the left of 2960 is opaque, and there they have not been affected by the radiation.

* Roy. Soc. Proc., 90 B, p. 33, 1917.



Profs. Browning and Russ in the 'Proceedings of the Royal Society.'

Photograph showing Bactericidal Action of Ultra-Violet Light.
The Bacteria to the right of 2960 A.U. have been killed.

PLATE VII.

A small quartz vessel was filled with the bacterial emulsion, and placed in front of the slit of the apparatus. The third spectrum on the plate is the absorption spectrum of this emulsion. It ceases about 2960 A.U., showing that everything beyond this is absorbed. Or, in other words, the bacteria absorb the radiations which are fatal to them.

Browning and Russ consider as a result of this and other experiments, that "from the clinical point of view there are two distinct regions of ultra-violet radiation :—

GROUP 1.—A portion which begins where vision fails, namely, 3800, and extends to 2960 A.U. These rays have no marked germicidal action ; they are capable, however, of penetrating a considerable thickness of human skin.

GROUP 2.—A portion which extends from 2960 to nearly 2100 A.U. These rays have very marked germicidal action, the region of maximum effectiveness being between 2800 and 2540 A.U. The penetrating power of these rays is, however, very small ; they are completely absorbed by as little as $\frac{1}{10}$mm. of human skin."

It should be noted that Group 1 is to be found in ordinary daylight ; Group 2 is not.

Chlorophyl.—The green colour of vegetation is due to chlorophyl, an extremely complex and unstable substance or group of compounds, the composition of which varies from one plant to another. It seems to have been developed for the purpose of acting as a light absorbing screen. To prepare a solution of chlorophyl take a quantity of freshly-chopped young leaves, boil in an evaporating dish, wash repeatedly in water, squeeze out the last of the water, place the material in a closed flask, cover it with alcohol, set it in a dark place and shake occasionally. The solution will be obtained in a few hours. It has a well marked absorption spectrum consisting of a band between B and C (*cf.* second spectrum, facing p. 6), another between C and D, two between D and E, and three indistinct bands beyond E. The solution fluoresces with a blood-red light.

The atmosphere contains carbon dioxide. The leaves of plants and trees absorb the carbon dioxide of the atmosphere,

assimilate the carbon, and return its other constituent, the oxygen, to the atmosphere. The largest proportion of the carbon of trees and vegetables comes from the carbon dioxide of the atmosphere. Now this assimilation of carbon takes place under the action of light, and in the green parts of the plant. Moreover, it is only the particular wave-lengths absorbed by chlorophyl that promote the action. If a series of test tubes each containing a green leaf is placed along a spectrum, after some time a liberation of oxygen can be seen in the tubes placed in the strong absorption band in the red of the chlorophyl spectrum. A similar evolution of oxygen takes place on the leaves placed in the other absorption bands, but it is not so marked, and more delicate means are required to establish its presence.

The carbon is built up by the chlorophyl into sugars and starch. This transformation requires the absorption of a very large amount of energy; in order to produce one gram of starch from carbon dioxide and water 4230 calories of energy must be supplied. Practically all the light energy absorbed is used in this chemical change—*i.e.*, in forming compounds of great potential energy. The construction and arrangement of the organs of the plant so as to obtain the proper exposure of chlorophyl and promote the process of photosynthesis, as it is called, has been the chief factor in the development of the shoot.

Generally speaking, chlorophyl is produced in the leaf only when the latter is stimulated by light, though some forms are capable of building and maintaining the substance in total darkness. When chlorophyl absorbs light it disintegrates. We thus have two processes, light stimulating the production of chlorophyl, and chlorophyl as a result of its own disintegration abstracting energy from the light wave, which is used for building up starch and sugars. The most favourable intensity for these processes is that of direct sunlight in the temperate zones.

What the exact nature of the processes is we do not know; conditions are too complicated, and modern physical ideas have not yet been applied to plant physiology. But since

the action is connected with the absorption bands of the chlorophyl spectrum, the first step must consist in the absorption of energy by electrons from the light wave, and the consequent destruction of the groupings which these electrons maintain. When this step is accomplished, the others follow automatically.

The importance of the photosynthetic action of chlorophyl can hardly be overestimated. It ripens the green grain on which we depend for our bread. When we look on an expanse of forest or green field, it is a striking thought, that all this vegetation has been chiefly constructed out of the invisible carbon dioxide of the air by the action of the infinitesimal light waves. And coal, our chief source of energy, has in like manner been derived from the atmosphere through the agency of the vegetation of thousands of years ago. Thus light is the life of the world.

CHAPTER X

PHOTOTHERAPY

Phototherapy.—Phototherapy, radiotherapy, and heliotherapy, the healing of disease by light, by rays, and by sunshine respectively, constitute a treatment used both in ancient and modern times, which has an extensive medical literature, but which has never established itself, and in which the average medical practitioner has not much faith. The public are, however, greatly interested in it, because it is applied to the two great scourges of modern times, tuberculosis and cancer. One out of every eleven women dies of cancer, and one out of every thirteen men, and tuberculosis is responsible for a fifth of the death-rate of the adult population. When a disease is so widespread as this and there is no certain cure, the public are naturally interested in any novel treatment.

Light rays—understanding the term in the widest sense and including under the designation heat rays, ultra-violet rays, X-rays, and the gamma rays of radium, as well as visible light—light rays may be expected to produce two actions when they fall on a body, a heating action and a selective action. The first always occurs, the latter only occasionally. Now heat is undoubtedly of value as a medical agent, as witness the employment of hot baths, Turkish baths, vapour baths, hot fomentations, etc. All these have their special uses according to the end which is to be attained, whether perspiration is to be promoted or the nerves stimulated, etc. Here we are concerned with the physical aspect of the matter; the physicist is interested to know what advantage there is in applying heat by means of visible light rays instead of, say, by the hot air and dark radiation from the tiles in a Turkish bath.

One essential property of all kinds of rays is that they can go through a body without heating it. Light rays, for example, go through clear glass without heating it, because they are not absorbed by the glass. Dark heat rays with a wave-length greater than 13,000 A.U. are absorbed by glass. The near infra-red is not absorbed by glass, and consequently does not heat it. This property of glass finds a very interesting application in the employment of glass frames for growing cucumbers and other vegetables under. Much the greater proportion of the sun's rays go through the glass frame without being absorbed; they then fall on the ground, heat it, and the ground sends out dark heat rays. But these heat rays have too long a wave-length to get back through the glass; they merely heat the under surface of the glass, and then the energy is radiated down again. So the frame is a veritable trap for the light energy; it gets in, but cannot get out again. The same reasoning also explains why rooms with glass roofs may become so insufferably warm in summer time.

Suppose now we have a thin plate of glass and immediately behind it a plate of copper. We might heat the arrangement in two ways. Dark heat rays of long wave-length might fall upon the glass, hot air might be driven against it; in this case the glass would warm up first, and the heat would then travel through to the copper. Or we might let light rays fall upon the glass; these would travel through the glass without heating it, pass into the copper, and be absorbed there. Then some of the heat might be conducted back from the copper to the glass.

Skin and blood are, to a certain extent, transparent to light. To prove this we have only to look at the sun with closed eyelids, or to hold a lamp close up to the eye, when the lids are closed tight. Then some red light will be seen shining through. The matter has also been investigated more elaborately; Darbois showed that a piece of photographic paper introduced into the mouth under the skin of the cheek between two watch glasses was blackened after one minute by a powerful beam of light directed on the outside of the cheek. This result seems, however, too striking. Freund

showed with a somewhat long exposure, that pieces of skin and horn about half a mililmetre thick transmitted blue, violet, and ultra-violet rays to about 3260 A.U. The blood circulating in the skin hinders to a marked extent the entrance of the chemically active rays; in an experiment made by photographing a spectrum through ·17 millimetres of blood practically no action on the photographic plate was discernible from a point half way between the F and G lines onward into the ultra-violet. The slightest trace of water absorbs all heat rays beyond 15,000 A.U., and it is to be assumed, that skin and blood absorb also everything there.

Owing, therefore, to its partial transparency to light, when the surface of the body is irradiated by light, the initial absorption of the energy must take place at a slightly greater depth than when dark heat or hot air or hot cloths are employed. But the difference is so small, $\frac{1}{10}$ millimetre or so, that it is of no practical importance. Any curative effect of light rays must therefore be due to a selective action, not to raising the general temperature, but to direct action on the linkings between certain atoms.

Of course a light bath cabinet fitted with glow lamps, inside which the patient sits naked on a stool with his head and neck protruding through a hole in the cover, has certain definite practical advantages as a means of administering *heat*. There is, for example, no other way by which the temperature can be so exactly regulated; it is only necessary to alter the number of lamps used or the strength of the current flowing through the lamps, and this can be done very easily. Also very high temperatures can be attained.

The Finsen Light Treatment.—The best known name in the region of phototherapy is that of Professor Finsen of Copenhagen, who worked for many years on the subject, from 1893 onwards. He had an institute for phototherapy at which he treated large numbers of patients; he was fortunate in obtaining help both from private individuals and the state, and in thus being able to carry his plans to completion. He was awarded a Nobel Prize for his work. His chief success was with the skin disease lupus, a form of tuberculosis, of

which he treated from 1,200 to 1,300 cases. It is stated that he obtained a cure or considerable improvement in between 90 and 94 per cent. of these cases. But his treatment is not much used in our own country at present, apparently because it is slow, tedious, and expensive.

Finsen used as his light source a powerful arc lamp taking a current of 80 amperes and having an intensity of 40,000 candle power. The rays were directed by quartz lenses on to the surface to be treated; they passed through water filters so as to eliminate their heat, otherwise they were too hot to be borne for any length of time without discomfort. A quartz disc pressed down on the irradiated skin; the pressure made the skin anaemic, and so the rays were able to penetrate further. The exposure was given for an hour or longer. There does not seem to be unanimity as to how the rays acted, whether by killing the tubercle bacilli, or by stimulating the granulation tissue.

The Leysin Treatment for Tuberculosis.—Since 1903 Dr. A. Rollier has been treating the victims of all forms of tuberculosis at Leysin by sunshine. At present he has nearly a thousand patients from all parts of the world, and the Swiss government maintains two clinics under him for its tuberculous soldiers. The illustrated papers have shown us pictures of convalescent children sitting at school in the sun and snow attired in nothing but bathing drawers; the winter sun at Leysin has a greater intensity than with us. Why the sun's rays should cure is not known. Dr. C. W. Saleeby refers to the heliotherapic paitent's blood as "running with liquid sunshine"; this is hyperbole. If it is a case of a selective action on the bacilli, the difficulty is that the first group of radiations (*cf.* p. 143) which penetrate the skin are not bactericidal; the second bactericidal group are neither present in sunshine nor do they penetrate the skin.

Sunshine and Rickets.—Recently cases of infantile rickets have been reported cured by the use of exposures of the entire body to the rays of a mercury vapour lamp at a distance of 3 feet for three to twenty minutes every few days. Exposure to sunlight had the same curative effect. The

cure was due to the action of the light, because unexposed infants receiving the same diet did not show improvement.

It is possible to produce rickets artificially in rats by giving them a diet low in phosphorus, and use these rats experimentally for testing the efficacy of the different rays. According to Hess *, when tested in this way, it was found that the curative rays were 3,000 A.U. in length or shorter. The experiments were decisive. Window glass cuts out all rays with a wave-length shorter than 3350 A.U. or thereabouts, so the sun's rays had no curative action when they passed through a window before reaching the skin. This is apparently in accordance with Dr. Rollier's experience in treating tuberculosis. According to Hess in treating children a white flame arc lamp is preferable to the quartz mercury arc, as it contains less of the short ultra-violet rays, not contained in sunshine, which are especially irritating to the skin. The infants were exposed to a 30 ampere arc of this type at three feet daily for 30 minutes, or at nine feet for an hour.

There have been two schools of thought with reference to rickets. According to the one view the disease is due to a deficiency of a vitamin—the fat soluble vitamin A—which promotes growth. Vitamins are substances without the presence of a very small quantity of which the body is unable to derive the proper nourishment from its food. According to the other view the disease is due to confinement and defective hygiene. The two views are probably complementary, not contradictory. In many cases a course of cod-liver oil has been very successful, apparently because it supplied the lacking vitamin.

It has been suggested that sunlight or ultra-violet light sets up inflammatory and sub-inflammatory processes in the skin which produce vitamin A by a photochemical reaction. This would account for the seasonal prevalence of rickets in winter and early spring. The matter is, however, still very hypothetical.

While we are dealing with the action of sunlight on the skin attention may be called to an extremely rare disease, con-

* *Lancet*, 1922, II., 367.

genital porphyrinuria. In this disease owing to some error of digestion pigments are produced in the body which colour the urine red, colour the teeth pink, colour the bones, etc. These pigments are sensitive to light, and every summer, owing to photochemical action, inflammation is set up on the skin of the exposed parts of the body. The condition is, as has been mentioned, an extremely rare one; only about twenty cases have been described.

Why is the Sky Blue?—The atmosphere absorbs light. This is quite evident from the colour of the sun at dawn or sunset, when the rays have to travel through a much greater thickness of air before reaching us. It is then very much redder than at midday, showing that the red end of the spectrum is more penetrating than the blue end. Air molecules or dust particles in the atmosphere, it is not clear which, scatter the light which falls on them; they scatter the blue to a much greater extent than the red. Consequently when a beam of white light goes through the atmosphere, it gradually acquires a red colour owing to the blue being scattered out of it. The sky is visible by scattered light; hence it is blue. And the sun at sunset which is viewed by light transmitted through a great thickness of air is red. It is redder still when seen through a fog or mist; then in addition to air or dust there are smoke particles or vapour particles to help in the scattering.

The Mountain Sun.—When the solar spectrum is photographed by means of quartz lenses and prism, it is found to stop very suddenly at 2930 A.U. Increasing the exposure considerably does not help much; we only get a very little further into the ultra-violet. But the height of the sun in the heavens is very important. Cornu photographed its spectrum at different times during the afternoon, keeping the duration of exposure constant, and obtained the following results:—

Time	0^h2	1^h50	3^h40	4^h38	5^h14
End of Spectrum... ...	2950	2970	3045	3070	3150

Thus as the thickness of air penetrated by the rays diminished, the end of the spectrum moved further into the ultra-violet.

This can be explained only by assuming that the air absorbs the ultra-violet rays. This absorption is something quite different from the scattering described in the previous section; it represents a change of the energy of the light wave into heat or into energy of chemical or electrical change in the molecule.

We can diminish the thickness of air through which the sun's rays have to travel to reach us by climbing a mountain. It is well known that the pressure of the barometer diminishes, as we go up a mountain, by about 1 inch for every 900 feet. Cornu calculated from his photographs that the end of the solar spectrum should shift 10 A.U. further into the ultra-violet for every 663 metres of ascent. He tested the calculation by taking a photograph on the Riffelhaus in Switzerland, which is 2,570 metres or 8,432 feet high; this photograph gave a height of 868 metres for a shift of 10 A.U. At a later time Simony took photographs on the Peak of Teneriffe, which is 3,500 metres high, and found that an ascent of 831 metres was necessary to produce a shift of 10 A.U. Considering the difficulties of the experiment and assumptions involved in the calculation, this was quite a satisfactory agreement.

Thus the mountain sunshine has a quality which the sunshine of the valleys and plains has not; it contains certain ultra-violet radiations which the latter lacks. At first sight 10 or 20 A.U. may not seem worth climbing the mountain for. But the fact that there are more of the limiting radiations at high altitudes means that more are being absorbed there; now the absorption of ultra-violet light is often accompanied by ionisation—*i.e.*, in this case by change in the electrical condition of the atmosphere. This may make the air fresher. What exactly constitutes fresh air is not known. It is not merely sufficient to diminish the carbon dioxide content, as was formerly thought to be the case. Everyone admits that thousands of cubic feet of air may be pumped through a room and yet leave it with a close feeling. There are subtle changes in the condition of the molecules that defy chemical analysis, and yet conduce very much to our feeling of health. Possibly

the radiations present in mountain sunshine and absent from ordinary sunshine may bring these changes about.

Dangerous Light Sources.—Sunlight, as we have seen, stops at 2930 A.U. We are accustomed to it, and experienced in moderation it produces no injurious effects upon a healthy eye. If, for example, the eye is injured by gazing directly at the sun, it is because the latter is too bright, not because it contains injurious ultra-violet radiations. The same holds true with reference to all the illuminants in common use—oil flames, gas, incandescent mantle or electric bulb—they are all relatively weaker in ultra-violet radiations than the sun is, and perfectly safe to use. There are, however, some sources of light such as the quartz mercury arc or iron or tungsten arcs, used only for special purposes, which emit ultra-violet radiations of wave-length shorter than 2930 A.U. ; these cause a painful inflammation of the eyes and skin. To make them safe it is usually regarded as sufficient to place a sheet of window glass in front of them ; the injurious radiations are absorbed by the glass.

The quartz mercury arc consists of a quartz tube filled with mercury and mercury vapour at a low pressure and containing no air. To light it up, it is necessary to tilt the tube so that a mercury column forms from end to end ; an electric current flows along this column, the column breaks, and the tube is then filled with an intense green light. The quartz mercury arc is clean and easy to work, and its rays are sometimes used for medical purposes ; in this connection it is referred to as the "Artificial Mountain Sun."

While the ultra-violet radiations that pass through glass, or that are contained in sunshine, do not affect the normal eye, they may be injurious, if the eye is specially sensitive. In these cases spectacles made of Crookes' glass are worn ; this glass, which was introduced by Sir Wm. Crookes, has the property of stopping the ultra-violet radiations up to the end of the visible spectrum.

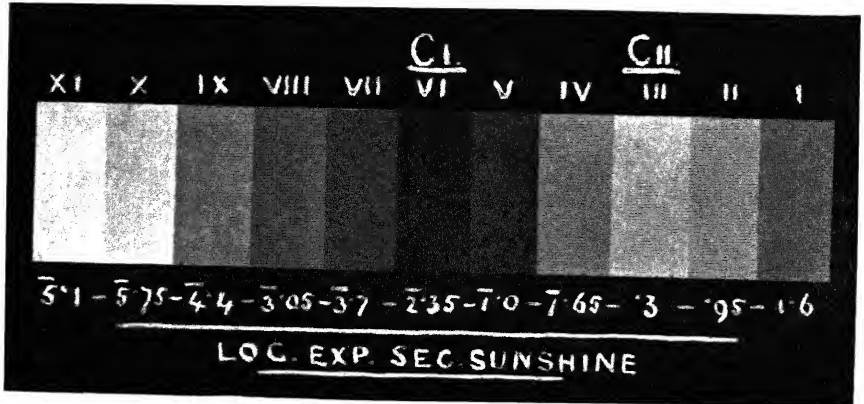
The Cooper Hewitt Tube.—A glass mercury arc lamp, the Cooper Hewitt tube, was put on the market for the purpose of lighting factories and workshops twenty years ago. It

consisted of a glass tube 27 inches long, and gave 500 candle power. At the time it was introduced it was a very economical means of lighting, and, owing to the length of the tube, it gave a diffused light with no sharp shadows, and consequently was suitable for a workbench. As the tube was glass, the injurious ultra-violet rays were absorbed. But the colour of the lamp was always against it; it gave everything a green, ghastly hue. Golden hair appeared a mossy green, a penny stamp was exactly the colour of a three-halfpenny one when illuminated by its rays, and I was told by some acquaintances who worked temporarily during the war on the night shift in a factory illuminated by the mercury arc, that the first night they opened out their sandwiches, they simply looked at them in the green light, and then tied them up again; the colour was too much for them. Various means of correcting the colour were tried by the makers, but none was very successful. So the lamp did not achieve a wide sale in its day, and it has been surpassed in efficiency by more recent lamps. But it still finds a use for advertisement purposes and for printing photographs.

Photographic Reversal.—We shall next give a short account of photographic reversal and the destructive action of infra-red radiation on phosphorescence. Both these phenomena have a bearing on the action of X-rays on the living cell.

If the exposure of a photographic plate is gradually increased, the density of the image, that is, the mass of silver reduced per unit area, also increases up to a certain point, the first critical point. If, however, the exposure is carried beyond this point, the density becomes less again, and the image is reversed. The reversal proceeds until a minimum of density, the second critical point is reached, after which the density increases again. The plate opposite which is the reproduction of a print obtained by J. Sterry, illustrates this very well. XI. is the least exposure, I the greatest, Ci the first reversal and Cii the second.

Professor Joly has suggested that the phenomenon is due to a state of tension in the latent image. The electrons expelled by the action of light become attached to surrounding mole-



Reproduction of a paper print by John Sterry, Hon. F. R. P. S. showing variation of density with increasing exposure. The exposures range from $\frac{1}{100000}$ second on the left, to 4 seconds on the right. It will be noticed that great over-exposure has diminished the density and then increased it again.

By permission of the Royal Photographic Society

PLATE VIII.

cules, and an electrostatic field is formed. After this field attains a certain strength, spontaneous neutralisation takes place, and the latent image is destroyed.

The explanation is, however, immaterial. The point to note is, that an excess of radiation here destroys the effect which it originally produces.

Effect of Infra-red Rays on Phosphorescence.—Certain substances, after being exposed to light, emit light for some time afterwards when placed in a dark room. The phenomenon is known as phosphorescence. It is the violet and ultra-violet parts of the spectrum that are most active in producing it. The duration of the emission after exposure to light varies very widely, Balmain's luminous paint, which is a sulphide of calcium, shines for hours in the dark after exposure to bright sunshine, while other substances cease to emit in a few seconds.

The phenomenon is quite distinct from the faint greenish-white light which phosphorus shows when exposed to moist air in the dark. The latter is due to slow combustion of the phosphorus. Once the phosphorus is consumed, it can never emit light again. But it is different with Balmain's luminous paint. When it ceases to shine in the dark, it is merely necessary to expose it again to the light, when it takes in a fresh supply of energy. The process may be repeated an indefinite number of times.

If a card which has been coated with Balmain's luminous paint is made luminous by a short exposure to sunlight, and then infra-red light is allowed to fall on certain parts of the cards, these parts rapidly lose their energy, and if the card is removed to a dark room, do not emit light at all.

So the infra-red radiations in this case destroy the effect which the violet radiations produce.

Radiotherapy.—After the discovery of X-rays in 1895 most attention was naturally given to their property of rendering opaque objects transparent. It became at once possible to detect the presence of foreign substances inside the human body, to examine fractured bones, the condition of internal organs, etc., and this branch of medical science to which

the name radiology has been given, and which has for its object the obtaining of accurate information about conditions inside the body has attained a very high development. Instantaneous radiographs, as they are called, can be taken, radiographs can be combined stereoscopically, the depth of objects below the surface of the body can be determined, and the success of X-rays as a means of diagnosis is great and beyond all question.

But shortly after their discovery they were also applied to the treatment of skin and other diseases. In this field their success has not been so great. There is no doubt of their power as an agent; X-ray burns, dermatitis or skin disease, severe ulceration of the skin, falling off of the hair and skin and finger nails as a result of undue exposure, showed at once that they must be used with great care. Their use as a means of treatment was no doubt suggested by the fact that ultra-violet light was already in use for the same purpose. Now there is one great difference between X-rays and ultra-violet in this respect. The latter only reaches the skin; X-rays can reach any required depth or go right through the body, according to the wave-length used

X-rays, as has already been stated, are merely light rays of extremely short wave-length varying from 5 to ·005 A.U. The lower limit gives the wave-length of the gamma rays of radium, which are of the same nature as X-rays. The shorter the wave-length, the more penetrating the rays. Rays of long wave-length are referred to as "soft," rays of shorter wave length—*i.e.*, the more penetrating rays, are referred to as "hard." The stopping power of a substance is roughly proportional to its density. By choosing rays of suitable wave-length it ought to be possible to reach lower depths without affecting the surface—*i.e.*, by choosing rays that go through the skin without absorption. They would then behave in a manner similar to the light rays in the experiment with the glass and copper plates described on p. 147. But the technique of the subject is hardly far enough advanced yet for the radiations to be separated in this way; very many different wave-lengths must be used at once.

Successful results have been obtained in treating rodent ulcers and ringworm by X-rays, but experience has shown that, as yet, they are no cure for cancer or malignant tumours. The difficulties of investigation have been extremely great. The rays must be focussed on the right spot, the right wave-length must be used, the right exposure given, and the right exposure for one patient may not be the right exposure for another. When the human factor is involved, experimental conditions can never be reproduced with the same exactitude as when dealing with inanimate objects. The photographer who has a camera with an imperfect focussing arrangement, no means of calculating his exposure, and an unknown brand of plates, could not take a very successful picture, and so can appreciate the difficulties that have occurred in radiotherapy. Also just as in the case of photographic reversal and just as in the action of infra-red rays in stopping fluorescence, so here, too, the application of a large dose of radiation may at times reverse the effect of a small one, and one wave-length may remove the effect of another.

With reference to the action of X-rays upon the cells of which the tissues of the living body are built, Professor Sidney Russ* says:

" . . . The effects are essentially selective. A measured dose of radiation of a certain wave-length which is sufficient for the destruction of one type of cell may be to all outward appearances without effect upon cells of a different variety.

"The effects produced by a certain quantity of radiation are largely dependent upon the way in which the rays are administered—*i.e.*, the dosage employed. For example, the effect of a single large dose of X-rays upon the human skin is greater than that produced by repeated small doses, the total quantity of radiation being the same in the two cases.

"There is at present no satisfactory explanation of the action which X-rays and the rays from radium have upon living cells. A good many facts have been ascertained, and some quantitative observations have shown that a wide range of sensitiveness to the rays exists in different types of

* *Science Progress*, 13, p. 605, 1919.

cells. Were it not for the fact that in many cases malignant cells are more affected by the X-rays than are the normal contiguous cells, there would obviously be little place for radiotherapy in disease. When we try to push investigation further in an endeavour to find out what processes in the activity of the cell are particularly influenced, it must be admitted that the information so afforded is scanty. Theories have from time to time appeared endeavouring to locate some specially vulnerable constituent of the cell, such as, for instance lecithin or the chromatin of the nucleus, or again the enzymes secreted by the cell. The evidence for these theories has hardly stood the test of criticism or further experiments, and it may be noted in passing that even though any one of these substances might be shown to suffer decomposition under irradiation it would tell us singularly little of the processes which, once established, lead to the destruction of the cell.

"Dosage may be graduated so that no actual destruction of the cell occurs, yet changes in its activity are induced; this may be shown by a reduced rate of growth which persists for many generations, without any recognisable histological changes in the cell or the structure of which it may form a part.

"With still smaller quantities of radiation the boundary line of what we may term "deterrent action" is crossed, and the phenomenon of stimulation makes its appearance."

CHAPTER XI

THE PSYCHOLOGY OF COLOUR

A dragon in the water covers itself with five colours; therefore it is a god.—*Chinese Text.*

Composing by Colour.—We shall introduce the subject of this chapter by three quotations. The first is from an article by Herman Darewski entitled "Composing by Colour," which appeared in the Christmas Number of *Pearson's Magazine*, 1916. In this article Mr. Darewski, who had then written the music of some thirty revues, told how he had discovered that colour helped him in his composition:

"In my case a very beautiful garden in summer time was the means of my coming to realise that colour does 'amount to something' for the musician. The garden belongs to a friend with whom I was staying and working at the time, and my room looked on to it. It was filled with the most glorious flowers, all of them bright hued. These flowers, unknown to me at the time, influenced my compositions; I found that what I had written in sight of them had a brightness about it that I somehow could not quite equal in music written in the ordinary way in dull, drab autumn and winter in London. Plainly the brightness of the flowers must have affected my mental outlook, and expressed itself in what I composed at the time.

"Having thus noticed that various colours had various effects upon me, I got a bunch of strips of coloured gelatines. There is every colour except black, and many shades among these strips. There are several reds, three or four blues, and so on. The next thing to do was to determine exactly what effect looking at the light through these colours had where I was concerned. I wanted to discover under what colour-influence I felt most lively, most melancholy, most bright, if

I may use the expression, most soothed, and so on. I was, of course, aware that bright red is generally regarded as the most irritating colour, and that green is restful ; but it would not have done to copy out a list of colours and their effects upon human beings, and rest content at that. The effect of colour upon one is largely an individual matter, I believe ; it depends mainly upon temperament.

" Here is what I have discovered various prime colours and shades make me feel :

Rich orange—reminiscent ; brings back the past vividly.

Deep blue Deep mauve	} depressed.
Orange Tango-red Yellow	} exhilarated ; in a bright, cheerful state of mind.

Grass-green—soothed.

Pale blue (not sky blue)—lonely.

Scarlet—irritable.

Pale amber—wealth of imagination.

Pale pink—fanciful ; inclined to extravagant imagination.

Purple—doleful.

Pale mauve—a sense of distance.

Pale moonlight (almost green)—a sense of space.

A combination of as many colours as possible, concentrated into a small circle—a chaotic mass of colours placed in a circle with black rim round a white background—amused ; ready to laugh easily.

" I do not pretend that every melody I write is composed under the mental influence and stimulus of colour, but it is a fact that colour has put me in the required state of mind—given me the desired conception or else quickened or enlarged conception—for practically all the tunes which I have written lately. Let me give some concrete examples.

" I had to write the music for a Russian snow scene for a certain revue. I sat and thought and I went to the piano and played, but I could not get the sense of dim vastness, of cold, of the jingle of sleigh bells satisfactorily blended together. In the back of my mind I knew vaguely what I wanted to

translate into music, but somehow I could not do the translation. My inspiration was stifled.

"Colour cleared away all the mental impediments, however. Looking through a deep blue strip of gelatine made me 'feel' the exact music which had previously eluded me, and, although I say it who should not, the result was what I regard as being one of the best bits of composition I have ever done."

Then Mr. Darewski goes on to state that he regards colour and tone as being brothers and sisters, and so much is he converted to the value of colour as a help to musical composition that he frequently resorts to its influence, even when he is more or less in the right mood for the work in hand at the moment. All his "numbers" in the revue *Razzle-Dazzle* were written under the influence of a combination of rich orange, tango-red (a kind of orange), and bright yellow light; these songs have lively, gay tunes. Hitherto his method has been to hold up bits of gelatine to the light and look through them, but he is having transparent screens of various hues made to fit over his study window.

An Architect's Views.—The next quotation appeared in the daily press during October, 1921, under such titles as "Colour and Health. An American Architect's Schemes. No more White Walls," and gives the views of Mr. William O. Ludlow, a New York architect. Writing on "Colour in the Modern Hospital," he reminds us that colour produces mental reactions, which are immediately reflected in bodily condition. The reactions are brought about partly by association of ideas, but aside from this, colour often produces real excitement or depression of the nervous system. He says:

"One cannot sit in a bright red room for any length of time with a feeling of comfort; we say the key is too high, which means that the nervous system is unduly stimulated. A blue room may be pleasant enough on a warm summer day, but the colour is not stimulating, and its great absorption of light, and particularly of the yellow rays, makes it devoid of cheer.

"White, except in great monumental work, is to be avoided,

for although it does not absorb the impinging light, it suggests sterility, coldness, and lacks all power to create pleasurable and helpful sensation. Green is a restful colour, and when used in the lighter shades particularly, makes an agreeable surrounding.

"The sunshine colours, gold, yellow, and buff, used on walls and ceilings in appropriate tones, bring to the inside of the house something of the joy of the sunshine, as we see it on fields and woods.

"During the period of recovery, the mind of the one in the hospital bed is perhaps more than usually responsive to the aspect of his surroundings. The tired eye that for ever roams over wall and ceiling until every crack is known by heart, craves something more positive than barren white walls; it wants objects of interest, such as pictures, stencilled patterns, hangings at the windows, and, above all, the repose and warmth that only colour can give.

"White is the winter colour, dazzling and brilliant, but is somehow reminiscent of winter's cold and cheerlessness. Let us, then, cover our hospital walls with colour, selecting those that give warmth and quiet, and that gentle stimulation that helps the patient along the road to recovery."

Light and the Insane. Our third quotation is from Turpain's *Lumière*, p. 272, and deals with a method of calming the insane by the use of coloured lights. Dr. Ponza, director of the lunatic asylum at Alexandria (Italy), in 1875 fitted several rooms with windows of coloured glass, and coloured the walls of each room the same as the glass of the window. The windows were numerous, and received direct sunlight during the greater part of the day. Principally violet and red rays were used. This was according to the advice of P. Secchi, the famous astronomer. "The colour violet," wrote the latter, "has an indescribably depressive quality which lowers one's spirits; this is doubtless why the poets have draped melancholy in violet garments. Perhaps violet light may calm the excited nerves of the maniac."

"After passing three hours in the red room a man afflicted with a taciturn delirium became gay and smiling; on getting

up the day after his entry into the same room, another madman who had refused all food whatever asked for breakfast, and ate with surprising avidity.

"A violent case who had to be kept in a straight waistcoat was shut in the room with blue windows; less than an hour afterwards he had become calmer. The action of the blue light on the nerves must be intense, as the following fact shows. Dr. Manfredi was led, blindfolded, into the different coloured rooms by a roundabout route so as to confuse his sense of locality, and recognised the blue room by a sense of oppression.

"A madman having passed a day and a night in a room with violet windows felt cured next day and left the asylum well."

Turpain also states that in the photographic factory of Messrs. Lumière at Lyons the manufacture of certain objects is carried out in a room illuminated by green light. It was found that when the hands worked all day in a red light they sung and gesticulated, and were very excited. But when green light was substituted, they became calm, and were less tired at evening. This happened in 1899.

Points on which there is Agreement.—There is much in the foregoing difficult to understand, but there are certain points connected with colour on which there is general agreement. It will be advisable to get clear ideas about the latter before going on to what is debatable.

We all enjoy colour. To work in a room with dead black walls and ceiling is undeniably depressing; I have done experimental work for hours at a time in a room of this nature, and was always conscious of low spirits towards the end of the period. The effect was undoubted, though not very marked. White walls and ceiling, on the other hand, are tiring and monotonous. After working in rooms or corridors painted a uniform white it is a relief to enter a room with colour, and even a small patch of colour in an otherwise white room, a green lamp shade or a picture or a crimson rug, sets it off immensely. It gives the eye something on which to rest. A certain amount of colour is necessary to the full enjoyment of life.

We all prefer our colours balanced. Just as an alternation of work and rest, hot and cold, sour and sweet, rough and smooth is desirable, if we are to have a full enjoyment of either, so the colour of a room should not be too red or too green or too blue or too yellow. If red is used, it should be accompanied by its complementary, peacock blue; the one colour sets off and enhances the other. Professor Munsell, in his *Grammar of Colour*, states that for comfort the colour should balance on middle grey; that is, if we take Maxwell's colour disc, and paint all the colours in a room on the disc, their areas on the disc being proportional to the areas which they cover in the room, then when the disc is spun, they should all merge into a grey of medium darkness. If they merge into a red, then the colour scheme of the room is unbalanced. In balancing colours it should be remembered that undiluted red, green, and blue (see colour triangle) are twice as strong as their complementaries, peacock blue, magenta, and yellow, and consequently should be used on smaller areas than the latter.

Professor Munsell's doctrine should, however, not be pushed too far. A want of balance is stimulating at times and prevents monotony; it is a change after too much balance. Also the form of the coloured objects and their degree of light and shade influence the balance; it does not depend on colour alone. But there is no doubt a substantial basis of truth in the statement, that as far as the taste of the average man goes, each colour should be accompanied or followed to some extent by its complementary.

It is also true that by training or environment we may always associate certain colours with certain objects. A child may have a favourite toy locomotive painted a peculiar shade of blue, and ever afterwards associate locomotives with this shade of blue. When as a man late in life he is looking at a locomotive, and this shade of blue involuntarily occurs to him, he knows why it does so; it is owing to the accidental association of childhood. The association of certain colours with certain ideas may also be cultivated artificially, for example, by painting a church door red to symbolise the blood of Christ.

Or the association may arise from a very natural metaphor; the phrases "white flower of a blameless life" and "keeping oneself unspotted from the world" spring from the common difficulty of leading a blameless life and keeping a white object clean.

According to Helmholtz the word red is connected etymologically with the Sanscrit *rudhira* = blood and also red. "Blue" is connected with the German *blau*, Dutch *blau*, old German *blaw*, and seems to come from the root of the English verb blow, and denote the colour of the sky, just as the Latin *cœruleus* is connected with *cœlum*. "Green" is from the same root as grow, being the colour of growing vegetation. "Yellow," German *gelb* and Latin *galbus* is connected with yolk and gold. The fundamental colours have thus taken their names from their association with common objects with which two of them, red and green, are still associated. The alleged exciting effect of red and soothing effect of green may be due to the association with blood and green fields respectively, not so much conscious association as subconscious racial memory. In the same way orange may be associated with sunshine, and bluish-green with moonlight.

The Difficulty and its Solution.—So far as we have gone, I think there will be general agreement. At least certain friends with whom I have discussed these matters, mostly honours science students, would subscribe to all the statements I have made so far. But the three extracts quoted go much beyond these statements.

If we take Mr. Darewski's table of colours and equivalent feelings, most of us would say it is too elaborate, that, if it is merely a matter of association, the effect of colour on one's spirits must be far too weak and vague to allow of the construction of a table like that. I have experimented with red and green; once when I had some hundred examination books to correct, I used a lamp with a window which might either be of red or green glass, and did the books at night by coloured light. The colours used were those of the railway signal lamps. I should have been exhilarated by the red and soothed by the green; I experienced no effect whatever either way.

As an alternative to dead black, a certain laboratory was painted a dull red, ceiling as well as wall. Red was chosen to prevent actinic rays from being reflected by the walls. The red was not relieved by any other colour in the room. I cannot say that the colour has had any appreciable effect on any one who worked in the room. And neither my friends nor myself would have thought it possible that any man's mood or ability to work could be influenced by looking through strips of coloured gelatine.

Mr. Ludlow's statement that a bright red room unduly stimulates the nervous system seems much too strong; the bright red would undoubtedly violate the observer's sense of taste, but his statement implies more than this.

Dr. Ponza's experiments are open to criticism, particularly the test made on Dr. Manfredi. We are dealing here with a psychological, not a photo-chemical effect of light. The blue rays do not fall on the face, and set up a chemical change there; to produce the psychological influence they must fall on the eye. This was impossible, since the man was blindfolded. It is much more probable that he recognised the room by smell or hearing. Also the account of the madman who refused all food, but ate his breakfast after he had been shut up all night in the red room, is open to ridicule. If you shut up a man in any room long enough without food, at the end of the period he will undoubtedly eat his breakfast with avidity, no matter what the colour of the room is. I have unfortunately not been able to obtain a fuller account of these experiments. But there is little doubt Dr. Ponza must have had some success with his treatment; he would not have gone to the trouble of preparing the rooms, and describing the results, unless he had success in some cases. There is also little doubt he would either consciously or unconsciously greatly exaggerate the successes; we usually find this done in any description of a new treatment.

Mr. Darewski's, Mr. Ludlow's and Dr. Ponza's statements are therefore evidence that colour can have a somewhat inexplicable influence on some people, much greater than I would expect from my own experience and the experience of

my friends. They, as already mentioned, were mostly honours science students, probably the class of man in whom one would be least likely to find any trace of an influence of this sort. Susceptibility to such an influence would, I think, be antagonistic to the acquirement of the habits of generalised and exact thought which science requires; if the susceptibility were ever possessed, it would become lost through disuse.

Curious Effect of Yellow. There are some additional facts which support the existence of such an inexplicable influence.

We have, of course, the infuriating effect of red on the bull. In the *Farbenlehre* Goethe states that he has known men of education on whom red had a similar infuriating effect; they "could not bear to see a person dressed in a scarlet cloak on a grey cloudy day." Then there is a very curious case of a man operated on successfully for cataract by Dr. Maitland Ramsay in Glasgow, and described by Professor R. Latta in the *British Journal of Psychology*, Vol. I. This man was blind, until he was operated on at the age of 30. He was intelligent, enterprising, and had acute hearing and a well-organised system of knowledge, before he received his sight. "The colour red gave him at once a feeling of pleasure; but dark colours did not specially depress him. Yellow, however, had a remarkable effect upon him. The first time he saw yellow he became so sick, that he thought he would vomit. This feeling has never recurred."

Coloured Thinking.—There is also the well-known phenomenon of coloured thinking, of which a very interesting account is given in Galton's *Inquiries into Human Faculty.* The coloured thinkers invariably associate some kind of colour with such things as the names of the days of the week, the hours of the day, the months of the year, the consonants, etc. A typical coloured thinker will tell you, for instance, that Sunday is yellow, Wednesday brown, and Friday black. These associations are fixed at a very early age, and are extremely definite. A coloured thinker is most fastidious in his choice of terms to describe the colours seen. The colours associated with particular concepts are unchangeable. Middle-aged people will tell you that for years there has been no

alteration in the colour or tint associated with certain objects. The condition is a hereditary one. It results from nature, not nurture. There is a most complete want of agreement between the colours which different coloured thinkers associate with the same concept. According to Galton, to ordinary individuals one of these accounts seems just as wild and lunatic as another, but when the account of one coloured thinker is submitted to another, who is sure to see the colours in a different way, the latter is scandalised, and almost angry at the heresy of the former.

Perhaps the nature of the condition will be made clearer if we quote from Galton, pp. 149 and 150, the accounts given by two coloured thinkers of their own peculiarity. The first is by the head teacher in a high school for girls. She says :—

"The vowels of the English language always appear to me, when I think of them, as possessing certain colours. . . . Consonants, when thought of by themselves, are of a purplish-black ; but when I think of a whole word, the colour of the consonants tends towards the colour of the vowels. For example, in the word 'Tuesday,' when I think of each letter separately, the consonants are purplish black, *u* is a light dove colour, *e* is a pale emerald green, and *a* is yellow ; but when I think of the whole word together, the first part is a light gray-green, and the latter part yellow. Each word is a distinct whole. I have always associated the same colours with the same letters, and no effort will change the colour of one letter, transferring it to another. Thus the word "red" assumes a light green tint, while the word "yellow" is light green at the beginning and red at the end. Occasionally, when uncertain how a word should be spelt, I have considered what colour it ought to be, and have decided in that way. I believe this has often been a great help to me in spelling, both in English and foreign languages. The colour of the letters is never smeared or blurred in any way. I cannot recall to mind anything that should have first caused me to associate colours with letters, nor can my mother remember any alphabet or reading book coloured in the way I have described which I might have used as a child. I do not

associate any idea of colour with musical notes at all, or with any of the other senses."

The second account is by the married sister of a well-known man of science. She writes :—

"I do not know how it is with others, but to me the colours of vowels are so strongly marked, that I hardly understand their appearing of a different colour, or what is nearly as bad, colourless to anyone. To me they are and always have been, as long as I have known them, of the following tints :—

"A, pure white, and like china in texture.

"E, red, not transparent ; vermilion with china white would represent it.

"I light bright yellow ; gamboge.

"O black, but transparent ; the colour of deep water seen through thick clear ice.

"U purple.

"Y a dingier colour than I.

"The shorter sounds of the vowels are less vivid and pure in colour. Consonants are almost or quite colourless to me, though there is some blackness about M. . . .

"Of my two daughters, one sees the colours quite differently from this (A, blue ; E, white ; I, black ; O, whity-brownish ; U, opaque brown). The other is only heterodox on the A and O ; A being with her black, and O white. My sister and I never agreed about these colours, and I doubt whether my two brothers feel the chromatic force of the vowels at all."

Coloured Hearing.—Closely allied to the condition of coloured thinking is coloured hearing. According to Professor Harris in an extremely interesting article on coloured thinking in *Science Progress*, July, 1914, a case of coloured hearing was described by Benjamin Lumley as long ago as 1864 in his *Reminiscences of the Opera*. "I know a person," he wrote, "with whom music and colours are so intimately associated that whenever this person listens to a singer, a colour corresponding to his voice becomes visible to his eyes ; the greater the volume of the voice, the more distinct is the colour." This person heard Mario's voice as violet, Sims Reeves' as gold-brown, Grisi's as primrose, and so on.

Attempts to Explain Coloured Thinking.—It has been suggested that in coloured thinking we have nothing more than the influence of some experience in childhood, which determined for us ever afterwards the colour of certain concepts. Baron von Osten Sacken, cited by Galton, states that his tutor taught him chronology, when he was 10 to 12 years old, by means of a diagram on which the centuries were represented by squares having narrow coloured borders, and it may be that in this way the recollection of certain figures became associated with certain colours. But he puts the explanation forward tentatively, without conviction. Professor Harris cites one or two similar cases. One observer thought of February always as white, because the earliest February remembered was snowy, and to a French observer, Monsieur Ch——, the vowel sound of i was suggestive of something *vive et gaie*, the colour green had always been associated with liveliness and gaiety, therefore he thought the vowel i was green. The sequence was "i"—"*vive et gaie*"—"green," but in course of time the "*vive et gaie*" had dropped out of consciousness, leaving only the "i" and "green" directly joined together.

But such explanations seem far fetched, and do not account for the strength of the association when they are given. In most cases they cannot be given. And Professor Harris has pointed out that if the influences of environment are operative in a large number of cases, the colours for such concepts as the months of the year ought to be far more uniform than they are. "If August is white to one person, because it is the month of white harvest, then it ought to be white to all persons capable of receiving any impressions as to the colour of harvest. But to the vast majority of people it is perfectly absurd to talk of August having any colour at all; and, to the few who think it coloured, it has not by any means the same colour; all seems confusion."

Coloured thinking does not occur in the ordinary type of mental constitution, but in the slightly supernormal. There is nothing in it allied to mental instability. Some relatives of coloured thinkers may possess a high degree of artistic or

musical ability. And, of course, coloured thinking when it occurs, does not require to do so in an extreme form ; it may be present only to a slight degree. The tendency in musical criticism to describe voices and pieces in terms of colour makes one think that the musical critic often has it to a slight degree ; this is why his criticism appears at times meaningless to the average man.

There is a great variety of mental constitutions in the world. So to return to the original theme of this chapter, the effect of colours on the mind of the percipient, we may have two men gazing through the same coloured window. The photo-chemical changes in the retina may be the same in each case ; the nervous impulses along the fibres of the optic nerve may be the same in each case. The primary sensation—*i.e.*, the actual picture seen, may be the same in each case. But a strong secondary sensation, for example, a feeling of elation or discomfort, may be aroused in the one case which is quite lacking in the other. The undisputed manner in which sounds and concepts connect themselves with colours in the minds of the coloured hearers and thinkers make the converse effect, the production of moods and states of mind by colour, seem all the more natural. The percentage of cases in which colour operates in this way seems very small. Apparently no statistical investigation has ever been made to determine it. I have not met a single case myself. But in a book like this, which deals with the nature and effects of colour from the physical standpoint it is necessary to call attention to the existence of the effect, and state that there is no physical cause for it. It is a matter for the psychologist to explain.

Colour Music.—Mr. A. W. Rimington put forward the view that if different colours were thrown on to a screen, one after another in a rhythmical manner, after a suitable training the spectators would derive the same pleasure from witnessing the performance, as they do from hearing music. He wrote a book *Colour in Music* in support of his opinions, and devised an instrument with a keyboard like an organ for producing the changes of colour. From the fact that his experiments were well advanced in 1912, and that little has been heard of his

art, it is to be inferred that his views have not met with support. This is hardly to be wondered at.

There is no *a priori* reason for the spectrum producing the same effects as the octave. The analogy which Newton thought he had found was not a true one. It is true that the differences in colour of the spectrum are produced by differences in the length of the light waves, just as differences in pitch of the notes of the octave are due to differences in the lengths of the sound waves; it is also true that the wave-length of the red end is almost twice the wave-length of the violet end of the spectrum, just as the wave-length of the lowest note is twice the wave-length of the highest note of the octave, and that there is a similarity between violet and red somewhat reminiscent of the octave. But here the resemblance ceases; the colours of the spectrum are more like noises than musical notes. There is nothing similar to the phenomenon of complementary colours in the octave. We do not get the same sound when we press down C and G simultaneously on the piano, as we do when we press down D and A, though I have no doubt it would be possible to get two noises which, when produced simultaneously, would sound exactly the same as other two noises. We cannot get colour apart from form; there is nothing analogous to form in connection with sound. So, though the idea has occurred to many workers since Newton's time, there are no theoretical grounds for expecting the spectrum to produce similar effects to the octave. Of course, when the matter is tried experimentally, it may do so. But, if the name colour music can be applied with justice to a sequence of coloured lights, the justification must be based solely on the mental states produced by the arrangement and not on any analogy, real or fancied, between the spectrum and the octave.

It is undeniable that we take pleasure in displays of colour, sunset skies, fireworks, fairy fountains, etc. I myself have shown the spectrum of a mixture of thallium, lithium, and sodium to some hundreds of students; the salts were introduced into the bunsen flame, and the spectrum examined with a one-prism spectroscope with wide slit. It then consists of

three bright rectangles, red, yellow, and green, on a deep black background. The colours are much purer than can be produced in any other manner, and the sight is a most beautiful one. It never palls, and I can see from the manner in which it is received for the first time, that it gives more aesthetic satisfaction than a peal of bells or chords played on the piano. But there is nothing to be gained by making these rectangles appear or disappear rhythmically. We are all familiar with the electric signs used for advertisement purposes which go through a short cycle of changes automatically; we never associate them with music. There is nothing to be gained by adding rhythm to colour.

Music, as we now know it, developed by degrees from very crude beginnings. Rhythm was at first probably more important than pitch, and the first melody was a savage war cry or a sort of prehistoric college yell; the first musical interval arrived at is supposed to have been the descending fourth, which developed into the tetrachord and then into the octave. The development took thousands of years. A similar art of mobile colour, as it has been termed, may arise some day. But if it does it will develop on lines quite different from those on which music has developed. So far as we can see, the veriest beginnings have not yet been made, and the application of the term music to mobile colour effects is undoubtedly premature.

On Feeling Sound.—While it seems certain that the rhythmic play of coloured lights on a screen can never produce the same sensation as hearing music, there is a description * of an interesting series of experiments made by Professor J. G. McKendrick in Glasgow, in 1896, which indicates that in certain circumstances the skin can feel music. By means of a special apparatus a varying electric current was produced from phonograph records. This current was sent through the primary coil of an inducton machine. The wires from the secondary coil passed to two platinum plates dipped in weak salt solution. When the phonograph was set going, a high tension current of varying intensity passed through the

* Proc. Phil. Soc., Glasgow, 1896.

salt solution. Every sound wave recorded by the phonograph produced a vibration in the current. When the sound grew in intensity, the current grew in intensity; when the pitch of the note rose, the frequency of the vibrations of the current increased.

When the experimenter put his fingers into the beaker containing the salt solution, he felt the intensity, the time, the rhythm, and even the expression of the music of the record. Thus the nerves of the skin can be stimulated by irritation coming to it at the rate of the notes and chords of rapid music. To quote from the description: "You can *feel* the long drawn-out notes from the saxhorn or trombone. You feel the *crescendo* and *diminuendo* of rhythmic movements, and you can estimate the duration of the note and chord." But the skin cannot tell differences of pitch.

An interesting experiment was made with four patients from a Deaf and Dumb Institution. One of these had her hearing up till she was 11 years of age, and then she became stone deaf. She had undoubtedly a recollection of music, although she no longer heard any sound. She wrote a letter "in which she declared that *what she felt was music*, and that it awakened in her mind a conscious something, that recalled what music was. The others had no conception of music, but they were able to appreciate the rhythm, and it was interesting to notice how they all, without exception, caught up the rhythm, and bobbed their heads up and down, keeping time with the electrical thrills in their finger tips."

Number Forms and the Varieties of Human Faculty.—The general conclusion of this chapter is, that while colour does undoubtedly add to the comfort and enjoyment of life, it means nothing more than this to most people, but that there are certain abnormal or slightly supernormal people for whom it means more, whose mental states it may influence extremely, or who may mix it up with their thoughts in an inexplicable way. People gifted or afflicted this way are rare; they themselves may think there is nothing peculiar about their habit, or they may feel ashamed of it and conceal it, and so it escapes observation.

Reference has been made on p. 11, Chapter I., to the famous dictum of the Pythagoreans that "things were numbers," and it was said that perhaps this statement was intended to convey only the truth, that nature could be investigated mathematically. It was a natural way of putting the statement at a time when general concepts were not definitely distinguished from the phenomena by which these concepts were arrived at. Some of the statements of Philolaus, who was a contemporary of Socrates, probably older than Socrates, and the first Pythagorean to write an account of the system, go, however, considerably beyond this. He maintains, for example, that "two is opinion, five marriage, seven the opportune time." It is difficult for a modern to understand what possible meaning these statements ever had.

Perhaps an investigation of Galton's * may throw some light on the matter. Allied to the coloured thinkers, whom we have described above, there is another curious class of people, strong visualisers, who, whenever they think of numbers, think of them arranged in rows in space, in front of them, in some peculiar manner. The arrangement in which the numbers appear to them is called their "number form," and Galton gives representations of several typical number forms in his book. Suppose, for example, a person of this class were looking at a ship on the horizon, and were to think of the number 6, he would behold it solid, not in some sort of dreamland, but as distinct as the ship, in a definite direction, at a definite distance. The number 6 would always appear to him at the same place in his field of vision, and the other numbers, when they appeared, would always occupy the same positions with reference to 6.

Students of the early history of mathematics will know that the Pythagoreans were greatly concerned with square numbers, triangular numbers, arithmetical, geometrical, and harmonical progressions. A triangular number represented the sum of a number of counters laid in rows on a plane, the bottom row containing n, and each succeeding row one less:

* *Inquiries into Human Faculty and Development*, p. 114.

it was consequently equal to the sum of the series

$$n + (n - 1) + (n - 2) \ldots\ldots + 2 + 1$$

or to $\frac{1}{2}n(n + 1)$. The Pythagoreans thought of the numbers as points arranged in space. They were evidently strong visualisers. Some of them may have had number forms or allied peculiarities, and this may have contributed to the vogue of their celebrated dictum.

In any case, when studying the early history of mathematics, it is necessary to remember the great differences that exist in mental character. No man can lay his mind exactly alongside another's, unless they have had the same conditions of heredity and environment. There is no doubt, that if we knew more about the wide differences in human faculty existing at present amongst ourselves, we could study to greater advantage the thought of the past. The rare types we have among us may have occurred more frequently in the past. In studying Plato's doctrine of forms, for example, it is far too often assumed, that we moderns have all the one cast of mind, and that Plato was like us.

These are, of course, not idle speculations. It is only by studying past history and present capabilities that we are able to forecast history. And in order to direct our energies economically, it is extremely important to know what things are possible and what are impossible. Some of the relativists, for example, assert, that Einstein's views on space and time are quite as simple as the traditional views, that it is only because we have been educated in the traditional views that we find the new ideas difficult. If we knew more about the varieties of human capacity and how they have developed in the past, we might be able to state whether this assertion is true or not.

INDEX

Printed by Fox, Jones & Co., Kemp Hall Press, High Street, Oxford.